Modern Tunneling

With Special Reference to Mine and Water-Supply Tunnels

BY

DAVID W. BRUNTON

AND

JOHN A. DAVIS

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CHAPTER I

INTRODUCTION

PURPOSE OF BOOK

Up-to-date information concerning tunneling methods is difficult to obtain. There are but few books on the subject, and much of the material they contain, although it is very interesting and valuable historically, is now obsolete. The engineering periodicals, it is true, endeavor to keep abreast of the times and there are several of which scarcely an issue appears without some article bearing upon tunnel work. But the very multiplicity of these magazines prevents one from reading all of them regularly, and the foreman or superintendent in charge of a tunnel, or the mining engineer designing one, and especially the business man financing the project, has no time for a laborious search after scattered articles in order to determine the present status of tunnel work. Then, too, knowledge of new methods travels slowly. Inventions and improvements of definite and practical value in mining as well as all the other industries, and important discoveries in science, frequently remain in the note-book of the investigator, or, as theses, are buried in university libraries or may be published only in the very locally distributed journals of small scientific societies. In biology, the work of Mendel on heredity (whose experiments in his cloister-garden are the foundation of a new conception of the nature of living things on the part of biologists, which bids fair to exert an influence not less than that associated with the name of Darwin), although published locally by him in 1865, remained unknown to the scientific world until its simultaneous discovery by three independent workers in 1900. In astronomy, the invention of the achromatic lens, without which the modern telescope would not be possible, by John Dolland in 1758, was antedated some twenty-five years by the investigations of Chester Moore Hall. So also in tunneling, up-to-date methods and equip-

ment that are proving safe, efficient, and economical may be totally unknown outside the district in which they originate. This book is intended to supply, if possible, such data concerning tunneling methods in the United States, and to make suggestions that, it is hoped, may result in a saving to the mining industry of life, energy, and capital that would otherwise be expended for inefficient or useless work.

In most of the published accounts of tunnel work, the writers usually do not attempt to criticise the methods they are describing. It is customary for such articles to contain accurate descriptions of equipment, various phases of working operations, and occasionally figures showing the cost of the work, but rarely do they include a discussion of the means for preserving the health and life of the employees, or data bearing upon the choice and efficiency of equipment or an analysis of methods and costs. As a result, the reader in drawing conclusions is dependent wholly upon his own resources. In this volume, on the contrary, the making of such analyses will be a primary consideration. It is desirable, nevertheless, in an impartial, disinterested book of this character to use constructive rather than destructive criticism. For that reason emphasis will be placed upon safe, efficient, and economical methods, and upon good points of equipment, while bad practice and obsolete machinery will be ignored except, perhaps, as examples of the inadvisable or as they have some bearing historically. Thus the authors hope to set forth a guide for future work rather than an unillumined record of past or present achievement.

SCOPE OF BOOK

This book will be confined chiefly to tunnels and adits* for mining purposes, such as drainage, transportation, or development, but it will also include those which are used to carry water for power, irrigation, or domestic use, in which the essential

* It has been suggested by prominent authorities that the word "tunnel" be restricted to the designation of such nearly horizontal passageways as extend completely through a mountain or hill from daylight to daylight, and

features are practically identical with mine tunnels. Tunnels of this sort are generally driven through at least fairly hard rocks in contrast to ordinary soil, quicksand, and other heavy material of a treacherous nature, and they are practically never driven through modern river-bed deposits. It will not be necessary, therefore, to consider the special methods and equipment for tunnel work in such materials. A distinction will be made between tunnels or adits for which the excavation is wholly or in a large part in material containing no ore and those which follow the vein through any irregularity in direction. As far as possible, the discussion will be limited to the former, because in the latter instance the methods employed in driving along a vein are usually more akin to the distinctive operations for removing ore, and are, therefore, not so apt to be good examples of tunnel practice.

ACKNOWLEDGMENTS

In the preparation of this book valuable assistance has been received from numerous sources. The writers are deeply indebted to the officials of the New York Board of Water Supply, of the Los Angeles Aqueduct, of the United States Reclamation Service, and the Bureau of Mines, and to the officers, managers, superintendents, and foremen at the different tunnels, for favors granted, for information supplied, often at no little inconvenience, and, above all for that hearty co-operation which has been an unfailing source of inspiration. Many thanks, also, are due the

the words "adit" and "drift" be used only for similar galleries which enter from the surface and serve to drain a mine or furnish an exit from the workings, but do not continue entirely through the hill. Such definition is eminently desirable from a strict technical viewpoint and would undoubtedly result in a much to be desired precision of diction, but, although it was proposed over thirty years ago and the suggestion has been repeated several times since, it has been found difficult, if indeed possible, to establish it practically. The American usage of referring to any horizontal gallery as a tunnel, without considering its extent completely through a hill or not, is so firmly fixed in our mining literature (being used by authors and editors alike), and among practical mining men generally in this country, and is even embodied in the United States mining laws, that the proposed restriction has been thought scarcely justifiable in a practical work of this character.

manufacturers of equipment and materials used in tunnel work for their promptness and courtesy in furnishing catalogues, data of tests, and similar material, and in supplying photographs, blue-prints, and cuts, which have been of great assistance in the preparation of many of the illustrations in this volume. Obligation is also acknowledged for many valuable suggestions obtained from articles in engineering periodicals and from books on tunneling and related subjects.

CHAPTER II

THE HISTORY OF TUNNELING

The art of excavating underground passageways has been known to mankind for many centuries. The ancient Egyptians and Hindus employed it in the creation of many wonderful subterranean temples and sepulchers in hard rock, and similar monuments are found in the works of the Hebrews, Greeks, Etruscans, Romans, Aztecs, and Peruvians—in fact, of all ancient civilized peoples.

It is not surprising that the Egyptians, with their wonderful knowledge of quarrying as well as many other useful arts, should have been versed in methods of underground rock excavation. Remains of their work, some of which dates back to 1500 B.C., may be found in the grottos of Samoun, the tombs near Thebes and Memphis, the catacombs of Alexandria, and the temples of Ipsamboul. A gigantic tomb has been found at Abydos, which was cut in the solid rock during the Twelfth Dynasty by Senwosri III.; also Rameses II., who is perhaps the best-remembered personage of these ancient times, constructed, either because of vanity or the great length of his reign, many rock-cut temples, the grandest of which is probably that of Abu Simbel.

The work was performed with hand tools, and the labor necessary to have fashioned monuments of such magnitude and grandeur must have been stupendous. For cutting granite and other hard rock, the workmen used saws of copper which were either fed with emery powder or were set with teeth of that abrasive. A similar method was employed as early as the Fourth Dynasty for circular holes which were drilled by a tube having fixed teeth, or which was fed with emery powder. For removing rock in a quarry or in a tunnel, grooves varying in width from 4 to 20 inches were made on four sides of a block, which was then

broken out by the swelling action produced by soaking with water a number of wooden wedges driven into these grooves.

The excavations in India probably number at least a thousand, the majority of which are of Buddhist origin. They are usually of two types—chapels and monasteries. The former consist of a nave with a vaulted roof, separated from the side aisles by columns, and containing a small chapel at the inner circular end. The latter consist of a hall surrounded by a number of cells for the residence of monks and ascetics.

Most of the Indian excavations are of much later date than those in Egypt. The earliest, the Sudama, or Nigope, cave, was constructed probably about 260 B.C.; the Lomas Rishi was built about 200 B.C., and those of Nassick about 129 B.C. These earlier caves imitated very closely contemporaneous timber-roofed temples, and for this reason the columns all slope inward, copying with great fidelity of detail the rafter supports of the wooden temples. In the Karli caves (about 78 B.C.) this feature is absent; the columns of the nave are quite plumb and the perfection of architecture and ornamentation is unsurpassed by any of the later Hindu rock-temples. The galleries and rooms of the caves of Ellora contain a total of nearly five miles of subterranean work. Although the builders may possibly have known of gunpowder, it was not used in the construction of these tunnels, which, like all the preceding works, were accomplished laboriously with hand tools and probably by slave labor. The caves of Salsette belong to the sixth century A.D., while those at Elephanta were constructed about 800 and the Gwalior temples were excavated still later during the fifteenth century.

Modern archæological investigation indicates that tunneling was possibly known to the Minyæ, an ancient Grecian people dating back beyond 2000 B.C., whose cycle of myths includes, among others, that of the Argonautic Expedition. A series of shafts, sixteen in all, are to be seen near Lake Kopais in Bœotia, which are supposed to have been constructed by these peoples for the ventilation of an ancient drainage tunnel. The shafts are 200 to 1,000 feet apart, 6 to 9 feet wide, and have a maximum depth of 100 feet. The tunnel was probably the enlarge-

ment of a natural watercourse such as are commonly found in similar calcareous rocks. Krates of Chalcis, a mining engineer who lived in the time of Alexander the Great, is credited historically with an attempt to drain this lake by utilizing and enlarging natural watercourses.

Although the exact date of the introduction of mining into Attica, probably from the Orient, is unknown, it seems to have been subsequent to the time of Solon (about 600 B.C.). By 489, it is certain that the silver mines of Laurium were yielding a highly satisfactory return, and at the instigation of Themistocles, the net profits from them were applied by the Athenians to the construction of a fleet, so that these mines no doubt contributed largely to the prosperity and power of Athens. The workings, approximately two thousand in all, consisted of shafts and galleries in which the rocks were hewn out with hand tools and brought to the surface on the backs of slaves. Air was supplied to the large underground stopes or chambers by ventilating shafts about 6 feet square and from 65 to 400 feet deep.

Gold was mined in Macedonia and Thrace at least as early as the fifth century B.C., and Herodotus mentions a tunnel in the island of Samos built in the sixth century, which was 8 by 8 feet in cross-section, and nearly a mile long.

The Aztecs were well acquainted with mining, and they secured copper from the mountains of Zactollan, while the mines of Tasco furnished silver, lead, and tin; and the extensive galleries and other traces of their labor were of great assistance to the early Spanish miners. With no knowledge of iron, although iron ore was very abundant, their best tools were made of an excellent substitute in the form of an alloy of copper and tin. With tools of this bronze, they could not only carve the hardest metals, but with the aid of powdered silica they could cut the hardest minerals, such as quartz, amethyst, and even emerald.

Although the mines of the ancient Peruvians were little more than caverns excavated in the steep sides of mountains, nevertheless they knew of the art of tunneling, as is shown by tunnels of their aqueducts and by the extensive tunnel which they built to drain Lake Coxamarco. They, too, had no knowledge of

iron, and their tools were made of an alloy of copper and tin, which they probably discovered quite independently of the Aztecs, whom they rivaled also in the cutting of gems.

The Romans, however, were undoubtedly the greatest tunnel-builders of early history. They drove tunnels for passage, drainage, water supply, and mining, not only in Italy, but wherever their conquests led them, as is evidenced both by records and by old workings left behind in the countries they dominated. One hardly needs to mention the numerous aqueduct tunnels and sewers of the ancient city of Rome, some of which are in use to-day, attesting the ability of the Romans in this branch of engineering. Remains of their work, many of them remarkably well preserved, have been found in France, Switzerland, Portugal, Spain, Algiers, and even Constantinople.

Their tunnels were of no mean size. A road tunnel near Naples constructed, according to Strabo, about 36 B.C., was approximately 4,000 feet long, 30 feet high, and 25 feet wide. About 359 B.C., Lake Albanus, which lies about fifteen miles southeast from Rome, was tapped for its supply of clear water by a tunnel over a mile long, 8 feet high, and 5 feet wide. Possibly the greatest Roman tunnel was driven by the Emperor Claudius to drain the overflow waters from Lake Fucinus, which is situated about seventy-five miles nearly due east of Rome and has no natural means of outlet. This tunnel, completed in 52 A.D., after eleven years' labor, is over three miles long, and was designed to be 19 feet high and 9 feet wide; but it appeared to have been even larger than this when, in 1862, it was reopened to secure valuable land beneath the lake.

These works seem all the more marvelous when one considers the primitive methods available at that time. Explosives were unknown, and machinery was not then used in mining. Rock openings were usually made by chipping, by channeling and wedging, as in Egypt, or by cutting large grooves around the block to be excavated, using hand tools made of iron, copper, and bronze, although it is quite possible that for certain classes of stone-cutting, diamonds or some similarly hard minerals were employed in conjunction with primitive tube-drills and saws.

These methods were often supplemented by fire-setting, a method chiefly employed, however, in the large chambers or stopes, and not well adapted for driving small tunnels. It consists simply of heating the rock to a very high temperature and quenching suddenly with water (or sometimes with vinegar in calcareous rocks), producing shattering and disintegration because of sudden contraction. Many writers have described the intense and fearful sufferings of men engaged in this work, usually slaves and prisoners of war who perished by the thousands — a fact, however, of little concern to the ancient builders.

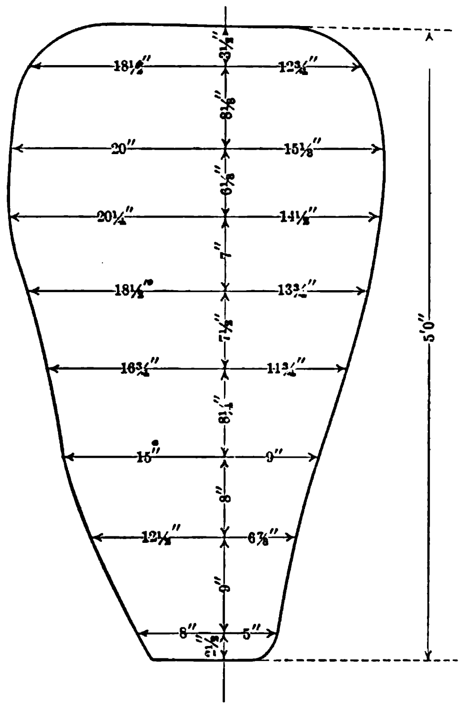

FIG. 1. Section of an old Roman adit in hard slate.

The value of Spain as a storehouse of precious metals, offsetting somewhat the influence of Eastern wealth, was well appreciated by Roman leaders, and an armed force for the protection of the mines was maintained there constantly, in many cases at the cost of serious political and financial embarrassment at home. In southern Spain, where the numerous silver and copper mines contained much water, Roman tunnels are very common. They are remarkable for their small size, being usually about 5 feet in height and, where timbered, from 16½ to 36 inches in width, a fairly typical one being shown in Figure 1. This adit, as far as explored, has a length of 1,850

feet and a maximum depth of 183 feet. The timbered openings are even smaller than this, a fair type of them being shown in Figure 2, which gives the dimensions of the openings and the timbers supporting it. The particular tunnel from which this section was taken is 2,300 feet long and has a maximum depth of 215 feet.

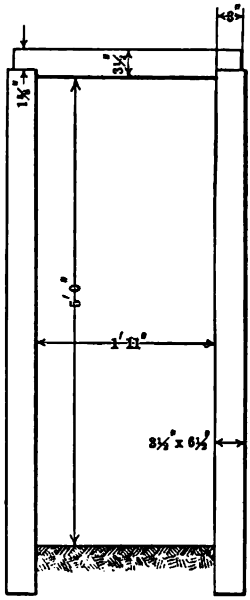

FIG. 2. Section of timbered Roman adit.

As nearly as can be ascertained today from discoveries in them of various objects of interest, including coins, it is certain that these adits must have been driven very early in the Christian era. Toward the latter end of the period in which these particular tunnels were used by the Romans, attempts were made to work the ore bodies below them by raising water from the lower stopes by means of slave-operated water-wheels.

Since artificial ventilation by means of blowers was at that time unknown, like most of the Roman tunnels, these were ventilated by shafts which were spaced in the tunnel illustrated above at about 25-meter intervals; in order, also, to minimize the depth to which the shafts were sunk, the tunnels corresponded very nearly in their course to that of the valleys or gulches above them, instead of being straight, as is the usual modern practice. Like the adits, the ventilating shafts were remarkably small. Where timbered, they were usually about 2 feet 10 inches square in the clear, and where the rock would stand without timbering they were circular and generally did not vary much from 2 feet 4 inches in diameter.

With the fall of the Western Empire, tunnel work in Europe practically ceased for many centuries. Some excavations were made, it is true, for tombs and the crypts of monasteries; and underground passages leading to a secluded exit, to furnish the occupants a means of escape in time of defeat, were a necessary

part of the equipment of each castle. Crude attempts at mining, also, were practiced in Germany. The Teutonic tribes, whose main occupation was warfare and who were savage, barbarous, and essentially nomadic at the time of the conquests of Julius Cæsar, had probably learned from the Romans the value of gold; later, somewhat tempered and softened possibly by the civilization they had destroyed, they began to search for precious metals and to pursue other peaceful occupations.

During the Middle Ages tunneling was devoted almost exclusively to the needs of war and was seldom employed for constructing aqueducts or other public works. There is, however, a record of a road tunnel begun in 1450 by Anne of Lusignan. It was intended to pierce the Alps at an elevation of nearly six thousand feet, and afford better means of communication between Nice and Genoa, but was never completed. Work was subsequently resumed in 1782 by Victor Amadeus III., but was finally abandoned twelve years later, after a total of nearly eight thousand feet of tunnel had been constructed.

Although gunpowder in Europe, according to the consensus of opinion, was probably invented early in the fourteenth century and by the end of the sixteenth century was very commonly used in military operations for gunnery and for blowing up fortifications, it was not applied directly to mining or tunnel operations during this period. Agricola's "Bergwerck Buch" * (published by Basel in 1621), the third edition of "De Re Metallica," pictures the Roman methods and of hand work and fire-setting as the usual means of mining at that time.

In the year 1613, Martin Weigel is said to have introduced gunpowder into mining work. Gatschmann describes the use of wooden plugs for tamping at this time, which were later (about 1685) supplanted by clay. August Bayer ("Das Gesegnete Markgrafenthum Meissen," 1732) and Henning Calvör ("Nachrichten über das Berg- und Maschinenwesen am Harze," etc.) also confirm the date of 1613 for the invention of drilling and blasting, but Honemann and Rössler make it fifteen or

* A complete English translation is now published. Hoover, H. C., and Hoover, L. H., De Re Metallica, 637 pp., London, 1912.

twenty years later. Whatever may have been the date when blasting was first used in mining, it is certain that the practice had become fairly common by 1650, for powder is mentioned as having been purchased for the Harz mines as early as 1634, drill-holes are reported at Düllen, which bear the date of 1637, and blasting is known to have been introduced into the Freiberg district in 1643.

The use of gunpowder in mining gave a new impetus to that industry which produced a large corps of men trained to overcome the difficulties of underground drifting, and it is not surprising therefore to note soon after an increased activity in tunnel work for other purposes. The chief of these allied interests was transportation, and in the eighteenth and early part of the nineteenth centuries a large number of tunnels were driven in connection with the canals, which, aside from wagon roads, were the only highways at that time. Later the development of steam railroads and the desirability of maintaining level gradients created a still greater demand for tunnel construction. A brief review will be given of the more important tunnels constructed for these purposes, both abroad and at home.

TUNNELS DRIVEN BY HAND-DRILLING

The first modern tunnel to be constructed for commercial transportation was the Malpas tunnel on the Languedoc Canal in France. It was 515 feet long, 22 feet wide, and 27 feet high, and was built between 1679 and 1681 * by Riquet, a French engineer. Although this tunnel showed that canals could be constructed through country before thought impassable, further advantage was not taken of this fact in France until nearly a hundred years later, when the Rive de Gier tunnel (1,656 feet long) was constructed on the Givors Canal in 1770, and the Torcy tunnel (3,970 feet long) on the Center Canal was built

* The writers wish to acknowledge their especial indebtedness to Henry S. Drinker, from whose monumental work on tunneling this and other valuable information concerning the earlier history of tunnel driving has been obtained.

in 1787. The Tronquoy and the Riqueval tunnels on the St. Quentin Canal were started in 1803 and the Noirou tunnel (approximately 39,400 feet in length), on the same canal, was begun in 1822. On the Bourgoyne Canal, the St. Aignan tunnel was started in 1824, so that by the middle of the nineteenth century nearly twenty canal tunnels in France had been constructed, having an aggregate length of nearly 93,500 feet.

The earliest transportation tunnel in England was the Harecastle, situated on the Grand Trunk Canal, which was begun in 1766 and opened for traffic in 1777. This tunnel was 8,640 feet in length, 9 feet wide, and 12 feet high. There were originally four other tunnels, but of shorter lengths, also on this canal. The Harecastle tunnel was found to be too small to accommodate the traffic through it, and was replaced in 1824 by a parallel tunnel, which was 16 feet high and 14 feet wide, 4 feet 9 inches of this width being used for a tow-path. The Sapperton tunnel on the Thames-Medway Canal was started in 1783. It was approximately 12,500 feet long, and six years were employed in its construction. The next large canal tunnel in England was the Blisworth (9,250 feet long), on the Grand Junction Canal, which was started in 1798, and required seven years for its completion. In 1856 there were over forty-five tunnels on the various English canals, aggregating some 220,000 feet in length.

The first canal tunnel in the United States was the Auburn tunnel at the Orwisburg Landing on the Schuylkill Navigation Canal. The tunnel (which was 450 feet long, 20 feet wide, and 18 feet high) was begun in 1818 and opened for traffic in 1821. The hill it pierced was composed of red shale, and the highest point was only forty feet above the top of the tunnel. The tunnel was shortened in 1834–37 and again in 1845–6, and was finally taken out altogether in 1855–6 by an open cut. The "Summit Level," or Lebanon Tunnel on the Union Canal, begun in 1824 and finished in 1826, was the second canal tunnel in this country. It was originally 720 feet long, 18 feet wide, and 15 feet high, being driven through argillaceous slate at a total cost of $30,464. It was followed by the "Conemaugh" and

"Grant's Hill" tunnels on the Western Division of the Pennsylvania Canal (1827–30), the Paw-paw tunnel on the Chesapeake and Ohio Canal (1836), and two tunnels on the Sandy and Beaver Canal, Ohio (1836–38).

The first railroad tunnel of which we have any record was the Terre Noire tunnel, near St. Etienne, France, on the Roanne-Andrezieux *horse* railroad. This tunnel, which was begun in 1826, was 4,920 feet long, 9.8 feet wide, and 16.4 feet high. Some fourteen other tunnels were built on the road from St. Etienne to Lyons between 1826 and 1833. The first tunnels on a railroad using steam locomotives were those on the Liverpool and Manchester Railway, constructed between 1826 and 1830. It was on this road that the famous trial between the "Rocket," "Novelty," and "Sans Pareil" locomotives took place in 1829. The following summary of early railroad tunnel-building in Europe is quoted from Drinker's "Tunneling," page 19.

"Tunnels, of course, multiplied rapidly in England with the extension of railways, and during the twelve or fifteen years following the construction of the Liverpool and Manchester line, there were a large number of tunnels built throughout the kingdom, among them being the famous Kilsby, Box, and Woodhead tunnels. The first tunnels on a steam railway in France were those built on the St. Germain line in 1837. Subquently, the ones on the Versailles, the Gard, and the Rouen lines raised the total length of tunnels in France in 1845 to 12,833 m. (42,105 feet). The report of the Corps des Ponts et Chaussées on tunnels for 1856 shows at that date a total on French railroads of 126 tunnels, of a total length of 65,106 meters. Among the noted early French tunnels may be cited the Nerthe, Arschwiller, Rilly, La Motte, Lormont, and Alouette. In Belgium, the Cumptieh tunnel, built in 1835, on the 'Chemin de l'Etat,' seems to have been the earliest. In Germany (Prussia and other States) the earlier lines were so located as not to require much tunnel-work; and Oberau tunnel (1839), on the Leipsic-Dresden line, in Saxony, was the first. In Austria, Rziha gives the Gumpoldskirch tunnel as the

first. A tunnel at Eriebitz (perhaps the same), on the "North" line, is mentioned in the Ponts et Chaussées Report (above cited) as an early Austrian one. In 1856 there were some fifty tunnels in Austria of a total length of 13,522 meters. In Italy, the Naples-Castelamare line, opened in 1840, had several tunnels. In 1856, the total Italian tunnels amounted to 10,181 metres; the Bologna-Pistoja line is especially remarkable for its semi-subterranean character. Among the early Swiss tunnels, especially to be noted is the Hauenstein, commenced in 1853 and finished in 1858."

The first railway tunnel in the United States was constructed on the Allegheny Portage Railroad in Pennsylvania, between 1831 and 1833. The tunnel (which was driven through slate) was 901 feet long, 25 feet wide by 21 feet high, and was lined throughout with masonry 18 inches thick. It was followed by the Black Rock tunnel (1835–1837) on the Philadelphia and Reading Railroad, and the Elizabethtown tunnel (1835–1838), on what is now the Pennsylvania Railroad; after this time, railroad-tunnel construction became so general that by 1850 as many as forty-eight tunnels had been completed on American railways.

Among the early European mining tunnels driven with gunpowder and hand-drilling, mention should be made of the Tiefe Georg and the Rothschönberger Stollen in Saxony, the Joseph II. Stollen at Schemnitz, Hungary, and the Ernst August Stollen, which was later driven under the Tiefe Georg. A number of tunnels, of which the Taillades tunnel was the most important, were also driven in connection with the Marseilles Aqueduct during this period.

The Tiefe Georg Stollen* was driven between 1777 and 1799. The total length of the main tunnel is 34,529 feet; its various branches aggregate 25,319 feet more, and yet this immense undertaking, driven entirely by hand, was carried out to obtain a drainage depth of only 460 feet. It passed through graywacke for nearly the entire distance.

* Drinker, p. 351.

Work was commenced on the Joseph II. Stollen, Schemnitz, Hungary,* in 1782, but owing to various interruptions the tunnel was not completed until 1878. The portal is at Wornitz, on the left bank of the River Gran, about ten miles west of Schemnitz. The tunnel is 10.27 miles long, 9 feet 10 inches high, and 5 feet 3 inches in width, and its cost was $4,860,000. It is used entirely for mine drainage and the annual saving in pumping amounts to over $75,000.

The Rothschönberger Stollen † was driven for the purpose of draining the mines of Freiberg, Saxony, and was commenced in 1844 and completed April 12, 1877. The tunnel starts in the Triebisch Valley at Rothschönberg, about 12 kilometers above Meissen on the Elbe. Its length on the line of the original location to Halsbrücke was 42,662 feet, but as completed to a connection with the Himmelfahrt, including its branches, had a total length of 95,149 and a depth below the Anna Stollen of 308 feet. Hand-drilling and black powder were used down to the end of 1875, when Burleigh drills were introduced. The work was carried on by the State, and perhaps no better example of the inefficiency of governmental control over industrial enterprises could be cited than the record of this work. The tunnel was nine feet square and was driven from eighteen headings, yet thirty-three years were required for its completion, the average rate of progress in each of the headings being only about 15 feet per month.

The Ernst August Stollen ‡ was driven below the Tiefe Georg Stollen in 1851–1864. The main tunnel is about 34,218 feet long, but the entire length of the adit and its branches is 74,452 feet, all driven in rock similar to that in the Georg Stollen quoted above. The tunnel is 11 feet high and 5½ feet wide, driven on a grade of 35.6 feet to the mile. Hand-drilling and black powder were used and, working seven-hour shifts, the rate of progress was fifty feet per month; four-hour shifts

* Wochenschrift des Œsterreichischen Ingenieur- und Architekten-Vereines, 1886, p. 284.

† Raymond, Trans. A. I. M. E., Vol. VI, pp. 542–558 (1877–1878).

‡ Drinker, p. 351.

FIG. 3. Starting a tunnel by hand-drilling.

increased the rate of progress to 78.7 feet per month, and by crowding the miners to the limit during the last three weeks they made 75 feet, or at the rate of 107 feet per month.

Some idea of the importance the early German miners attached to drainage may be gathered from the fact that this colossal enterprise only gave them an increased drainage depth of 315 feet.

The Taillades tunnel * on the Marseilles aqueduct was begun in January, 1839, and completed at the close of 1846. It was driven from fourteen shafts, and in their construction so much water was encountered that the work of sinking them was very difficult and at times seemed almost impossible. It was finally necessary to install at one of the shafts a steam engine of 100 horse-power in order to remove the water, which amounted to 3,300 gallons per hour. The cost of sinking the shafts was approximately $40 per foot, while the tunnel itself cost approximately $37 per foot, or, including the cost of the shafts, $48.50 per foot. The Assassin tunnel on the same project was somewhat less difficult and cost but $25.50 per foot for 11,400 feet, while the Notre Dame tunnel, which was lined with masonry for its entire length of 11,500 feet, cost $32.50 per foot.

The first large mining tunnel in the United States was commenced as early as 1824. This was the "Hacklebernie" tunnel near Mauch Chunk, Pennsylvania, and it was driven by hand-drilling and with black powder. When work on it was stopped in 1827, it had penetrated 790 feet through hard conglomerate, making an opening 16 feet wide by 8 feet high. Work in it was resumed once more in 1846 and the tunnel was extended to a length of 2,000 feet.

The invention of machines to do the work of rock-drilling, which occurred almost simultaneously with the discovery of high explosives, gave another great impulse to tunnel-driving. The first extensive utilization of these aids was in the construction of the Mt. Cenis tunnel in Europe and the Hoosac

* "M. de Mont. Richer et le Canal de Marseille." Félix Martin. Paris, 1878. Gallet et Braud.

and Sutro tunnels in this country. The success attained with them soon led to further activity in tunneling, not only for railroads but in connection with mining, drainage, and water supply as well—an activity culminating in the immense amount of such work undertaken within the last ten or fifteen years.

The following table gives in chronological order some of the more important events connected with these two wonderful improvements.

A SHORT CHRONOLOGICAL HISTORY OF HIGH EXPLOSIVES AND ROCK-DRILLS *

1847. Sobrero discovered nitroglycerine.
1849. J. J. Couch, of Philadelphia, patented on March 29 the first percussion rock-drill.
1851. J. W. Fowle, of Philadelphia, patented on March 11 the first direct-action percussion-drill.
1854. Schumann invented his percussion-drill at Freiberg.
1857. Schumann drills used in Freiberg mines.
1857. Sommeiller invented a rock-drill for use at Mt. Cenis.
1861. January 1, Sommeiller improved drills commenced work in the Mt. Cenis tunnel.
1863. Nobel first applied nitroglycerine as a blasting agent.
1865. Gun-cotton tried at the Hoosac tunnel by Thomas Doane, chief engineer.
1866. Nitroglycerine tried with great success at the Hoosac tunnel by T. P. Shaffner.
1866. Burleigh drills tried and proved to be a success at the Hoosac tunnel.
1867. Nobel invented dynamite.
1868. Dynamite patented in America by Nobel.

MINING AND WATER TUNNELS DRIVEN BY MACHINE-DRILLING

The idea of draining the mines of Virginia City by a deep tunnel was first broached in the spring of 1860, when Mr. Adolph Sutro began negotiations with the mines, the State, and

* Drinker, pp. 54–55.

finally with the Federal Government for contracts, concessions, etc. Actual work was first commenced at the portal of the tunnel in Carson Valley, three and one-half miles from Dayton, on October 19, 1869. The work was carried on by hand until September, 1872, when diamond-drilling was begun and experimented with, more or less unsuccessfully; in 1874, Burleigh drills were introduced, operated by compressed air generated in

FIG. 4. Driving a modern tunnel with machine-drills.

a compressor made by the Société John Cockerill, of Seraing, Belgium. The tunnel was completed July 18, 1878, when the Savage vein was cut 20,000 feet from the portal and 1,922 feet below its outcrop. The tunnel, inside of the timbers, was 10 feet high by 14 feet wide, divided into two passageways by a central row of posts. The rate of progress varied greatly, ranging from 19 to 417 feet per month, the average monthly rate from start to finish being 192.3 feet.*

* Report Commissioners Sutro Tunnel, and Drinker, pp. 337-350.

The Tequiquac tunnel, which now forms the most important link in the drainage system of the valley of Mexico, was commenced during the reign of the Emperor Maximilian. The work was stopped, however, at the fall of the Empire and was not resumed until 1885; even then the want of funds prevented any material progress until March, 1888.

This tunnel is six and a quarter miles in length, driven through a mass of sand, mud, and soft calcareous sandstone. It is brick-lined throughout, the section ovoid, with an extreme width of 13 feet 9 inches and a height of 14 feet and has a gradient of 1 foot in 1,388. The calculated flow is 450 feet per second, or 200,000 gallons per minute. At first the headings were driven in the center, but they were soon forced to adopt the bottom heading system. The greatest completed tunnel advance in any one month was 182 feet and the greatest distance that any single heading was driven in a calendar month was 656 feet. (Trans. Am. Soc. C. E., Vol. XXXII, pp. 171–267.)

The Kelty tunnel on the Glasgow Water Works System is 2.6 miles in length and 9 feet square. Work was commenced in June, 1887, and completed in December, 1889; driving was carried on from each portal and both ways from the bottom of two shafts. The average rate of progress in each heading was 4.5 feet per day. The rocks encountered varied from soft shale to hard conglomerate.

The Shoshone tunnel, 1906–1910, is owned by the Central Colorado Power Company, and its intake portal is located on the Rio Grande River, twelve miles above Glenwood Springs. It is 12,453 feet long, 12 feet high, and 16 feet 8 inches wide, and is driven for the entire distance through hard metamorphic granite.

Where timber supports were necessary, vertical posts and a three-piece arch were employed, all of which were afterward completely covered by concrete lining. Driving was carried on from seven cross-cut adits, as well as from both intake and discharge ends.

Cost of tunnel, not including concrete lining, was $927,653, divided as follows:

Construction costs per linear foot of tunnel:

Test drifts	$ .45
Drilling and blasting	20.66
Trenching and grading floor	1.15
Track work	1.76
Mucking and loading	17.28
Hauling	2.88
Dumping and maintenance	2.18
Blasting supplies	8.35
Drill steel	2.91
Sharpening and repairing	4.60
Timbering, temporary and permanent	3.87
Light and wiring	1.57
Ventilating	.59
Pipe, air hose, and connections	.85
Power drills	2.94
Hoists and trestles	.96
Pumping	.21
Sundries	.28
Total construction costs	$74.49
Overhead costs, including surveying, management, office, etc	30.91
Total cost per linear foot	$105.40

The Corbett tunnel, of the Shoshone Irrigation Project, Wyoming, is approximately 17,000 feet in length, of the inverted horseshoe type, having a cross-section about 100 feet in area. The tunnel heads opposite the Corbett Station of the Chicago, Burlington & Quincy R. R., and its course is parallel to the general direction of the Shoshone River, which at three places was near enough to permit adits to be excavated from the faces of the bluffs to the tunnel, thus affording eight headings for construction purposes. The contract for its excavation was awarded on September 16, 1905, the price being $33 per linear foot. In August, 1906, however, the contractor defaulted after having driven 5,219 feet of tunnel, and the work was taken over

by the United States Reclamation Service. After doing considerable retimbering the work was carried on without any special difficulties until its completion in 1907. The material excavated throughout the tunnel consisted of dry clay, loose shales, and stratified sandstones of different degrees of hardness, and it decomposed very rapidly upon exposure to the air, thus requiring considerable timbering.

The Big Bend tunnel, owned by the Great Western Power Co., is situated at Big Bend on the Feather River in Butte County, Cal. The main portion of the tunnel, about three miles in length, was driven by the Big Bend Mining Co., from 1883 to 1887, in order to divert the flow of the river across a narrow neck of land and leave the bend dry, allowing the company to work the gravels in its bed for gold. This tunnel was enlarged from 12 feet high by 13 feet wide to 18 feet high by 14 feet wide, and extended 3,400 feet by the present owners in 1907–1908. The entire tunnel is driven through shale with the exception of about 6,000 feet in the middle of the old tunnel, which is in diorite. It is lined with concrete about 29 inches thick, with an allowable minimum of 6 inches on the arch and 4 inches on the invert.

The Coquitlam tunnel, which is part of the hydro-electric power system supplying Vancouver, B. C., and neighboring towns, is 12,650 feet long and is driven through solid granite. As originally designed it had a mean sectional area of 81 square feet. Work of enlarging the tunnel so that it would have a sectional area of 176 square feet was begun in November, 1908, but was seriously handicapped by the necessity of opening the tunnel frequently to maintain the supply of water in a storage reservoir, but it was finally completed in March, 1911. The new tunnel is ovoid in cross-section with the point down and is unlined.

The Big Creek tunnel, which is part of the system of the Pacific Light and Power Corporation, is 22,000 feet long and 12 feet in diameter. It was driven from nine adits and two portals, has a slope of 3.2 feet per 1,000, and will be used as a pressure tunnel throughout, the static pressure at the upper

end being approximately 30 feet and at the lower end approximately 100 feet. The formation pierced was solid blue granite throughout, except for an occasional faulted zone. These were lined with concrete, the aggregate length of such linings being 2,000 feet.

RAILWAY TUNNELS

While this book is intended to deal chiefly with the construction of mining tunnels, there is much that can be learned from the study of tunnels driven for railroad purposes. Under ordinary conditions the rate of progress in a railroad tunnel is limited by the speed at which the advance heading can be driven, and as these *headings* do not differ materially from mining tunnels, the rates of progress which have been attained in them are of great interest to the miner. A railroad-tunnel heading must be driven to line and grade the same as a mining tunnel, and while it is desirable to maintain a uniform width and height, it is not absolutely necessary to do so, thus giving railway-tunnel headings a slight advantage over mining tunnels in this respect. On the other hand, the multifarious operations carried on between the heading and the portal of a railroad tunnel, even under the best possible organization, often obstruct temporarily transportation to and from the face; the continuity of the work is sometimes interfered with by the shooting of the benches back of the face; and even where all the holes in the benches and headings are blasted together, it takes somewhat longer to clear out the smoke from so many groups of shots than it would in a mining tunnel from a single round in the heading. On the whole, in similar rock and with equally good equipment and organization, there should be little if any difference in the speed attained in driving a mining-tunnel or a railway tunnel-heading, because, although the conditions for rapid progress are not exactly identical, the opportunities are practically equal. The history of the more important railway tunnels of the world also shows forcibly the rapid increase in the rates of driving and the lessening of the cost of construction since the introduction of rock-drills and high explosives.

PROGRESS AND COST OF SOME FAMOUS RAILWAY TUNNELS

	Construction Period	Length, Miles	Duration Boring, Months	Avg. Daily Progress in Headings, Feet	Cost per Linear Foot
Mt. Cenis	1857–1870	7.97	157	4.4	$356.00
Hoosac	1858–1874	4.75	...	3.0*	398.00
St. Gothard	1872–1882	9.26	88	6.2	231.00
Arlberg	1880–1883	6.2	40	13.6	162.30
Simplon	1898–1905	12.4	78	13.69†	239.40
Loetschberg	1906–1911	9.3	54	14.2‡	211.00

* Average east and west headings, 1865–1873.
† Allowing only for days on which drilling was carried on, advance was 17.45 feet per day.
‡ Average for last 30 months, 17.1 feet.

The Mt. Cenis tunnel was driven through the northern spur of the Cottic Alps to afford direct connection between the French and Italian railway systems. Work was begun on August 18, 1857, and the French and Italian headings met on December 25, 1870. The length of the tunnel as completed was 42,157 feet and the cost $15,000,000, or $356 per linear foot. Its greatest depth below the surface was 5,275 feet, where the rock temperature was 85° F. The Sommeiller rock-drill, operated by compressed air, was first used in this tunnel January 12, 1861, or five years before the introduction of air-drills into the Hoosac tunnel in the United States. The rate of progress varied greatly with the rock encountered; the total time consumed in driving being thirteen years and one month, or an average daily progress in each heading of 4.4 feet.§

One of the most important early tunnels driven in the United States was the Hoosac, on the line of the Troy & Greenfield Railway. The project first came under consideration in 1825, but actual work was not commenced until 1858. Hand-drilling was employed until October 31, 1866, when Burleigh rock-drills were first introduced; two months later nitroglycerine was substituted for black powder, and the net result of these two most important improvements was greatly to increase the rate of driving. To be sure, many disheartening delays and interrup-

§ Drinker, pp. 354–357. Vernon-Harcourt, Pro. Inst. C. E., Vol. XCV, pp. 249–261.

tions occurred, due chiefly to failure of the earlier type of drilling machines and to change of engineers and contractors, but in March, 1869, a contract was let to the Shanly Brothers, of Toronto, who completed the work on December 22, 1874.

The tunnel had a total length of 4¾ miles and was driven throughout the greater part of that distance in mica-schist. The maximum speed attained in a single heading was 184 feet in one month of twenty-six working days, and the average speed in the east and west headings for the last six months was 4.2 feet per day. The cost was $10,000,000, or $398 per linear foot.*

The great undertaking of driving the St. Gothard tunnel was rendered possible through a joint treaty made by Germany, France, and Italy, and on May 7, 1872, a contract for the tunnel was let to M. Favre, of Genoa, who gave a bond for $1,600,000 for the successful completion of the work within a period of eight years. The tunnel is 48,887 feet, or 9.26 miles, in length, driven for the most part through various kinds of schist. After testing a number of drills, a final selection was made of Ferroux drills for the north side and McKean for the south side. The average rate of progress in the headings was 186 feet per month. In 1880 one of the headings passed through a zone of softened feldspar, which, under the weight of the superincumbent rock, squeezed into the tunnel with such force that granite walls and arches 6 feet 7 inches in thickness were required to hold it in place. The maximum rock temperature encountered was 88° F., at a point 5,575 feet below the surface. The headings met February 29, 1880, but the tunnel was not completed until 1882, nearly two years after the time called for in the original contract. The total cost was $11,300,000, or $231 per linear foot.†

The success of the Mt. Cenis and St. Gothard tunnels, coupled with the desire of the Austrian Government to have a railway route to France which would not pass through Germany or Italy, led to the construction of the Arlberg railway, which runs from Innsbruck, in the Tyrol, to Bludenz, near the Swiss frontier,

* Drinker, pp. 315–337.

† Drinker, pp. 359–370. Vernon-Harcourt, Pro. Inst. C. E., Vol. XCV, pp. 261–268.

a distance of eighty-five miles, piercing the Arlberg range about twenty miles from Bludenz by a tunnel over six miles long. In the selection of the machinery and in planning the work, advantage was taken of the experience gained in the Mt. Cenis and St. Gothard tunnels. In consequence of this, the results obtained were as much in advance of the St. Gothard as the operations in that tunnel had been an improvement on those employed in the Mt. Cenis. The driving of this tunnel was commenced in July, 1880, and the headings met on November 13, 1883. The average rate of progress was thus nearly two miles per year. The greatest temperature of the rock was 64° F. at a point 2,295 feet below the surface. The Ferroux percussion drill, operated by compressed air, was employed in the eastern heading, and the Brandt rotary drill, worked by water pressure, in the western. The Ferroux drills drove 17,355 feet and the Brandt drills 14,880 feet, a difference of 2,475 feet in favor of the former. This variation was due more to the dissimilarity of the rock in the east and west headings than to any difference in the efficiency of the drills themselves, as is shown by the following figures, the average daily advance of the two drills being as follows:

Ferroux	Brandt	Year
13.5 ft.	9.5 ft.	In 1881
17.2 "	15.1 "	In 1882
17.85 "	17.82 "	In the 10½ months of 1883

These figures show that as the nature of the rock became similar when the faces approached each other, the efficiency of the Brandt drill was practically the same as the Ferroux. The Brandt drill was much more cheaply operated than the other, and it necessitated the use of only seven miners in the heading as against twelve with the Ferroux.

The total length of the tunnel was 32,235 feet and its cost was $5,877,684, or $182.30 per linear foot.*

* Vernon-Harcourt, Pro. Inst. C. E., Vol. XCV, pp. 268–271. Charton, "Le Génie Civil," Vol. VI, 1885, pp. 3–18.

The Simplon tunnel consists of two parallel, single-track railway tunnels, 56 feet from center to center, driven from Brigue, Switzerland, to Iselle, Italy, a distance of 12.4 miles.

Operations commenced at Brigue November 22, 1898, and at Iselle December 21, 1898. The headings met February 24, 1905, but the tunnel was not completed and ready for use until January 25, 1906. Brandt rotary hydraulic drills were employed in both headings and the average rate of heading advance was 13.69 feet per diem, although when conditions were favorable speeds of 16 feet per day in the Italian end and 20 to 21 feet in the Swiss end were readily attained. The rock was principally gneiss, with occasional beds of slate, granite, and marble.

When operating in hard rock, the cycle of operations was as follows:

Bringing up and adjusting drills............	20 minutes
Drilling................................	1¾–2½ hours
Charging and firing.......................	15 minutes
Mucking...............................	2 hours

More serious difficulties were encountered in driving this tunnel than any which have yet been undertaken. Swelling ground was extremely common, and in places the pressure was so great that the roof and sides could only be held in place by steel I-beams, with the spaces between rammed with rapid-setting concrete. A portion of the tunnel where the pressure was the greatest is said to have cost $1,620 per linear foot. Many springs were encountered, and the volumes of cold water flowing into the tunnel amounted at times to 17,000 gallons per minute. Near the center of the tunnel large springs of hot water were encountered, amounting in all to 4,330 gallons per minute, one spring alone giving 1,400 gallons per minute at 116° F. At first it seemed that the high temperatures engendered would effectually prevent further advance, but by bringing both cold water and cold air into the headings in sufficient volumes, the temperature was reduced to a point where it was possible to resume work, although it took six months to drive the last 800

feet. The rapid average rate of progress maintained in the Simplon tunnel, in spite of the difficulties encountered, was due to superb equipment and an organization so efficient that 648 men and 29 horses at the Swiss end and 496 men and 16 horses at the Italian end were advantageously employed.

Notwithstanding the care that was taken in ventilation and the precautions adopted for the health and safety of the workmen, sixty men were killed during the progress of the work. The total cost of tunnel was $15,700,000, or $239.40 per linear foot.*

The Loetschberg tunnel was driven through the Bernese Alps in Switzerland and forms the last link in the railway system connecting the city of Berne with the village of Brigue at the north end of the Simplon tunnel. The desirability of connecting the Bernese Oberland with the Rhône Valley was discussed as early as 1866 and the present location of the tunnel was first proposed in 1889.

The railway begins at Frutigen in the Bernese Oberland, about 32.5 miles from the north portal; 50.5 per cent of this length is on horizontal curves. There are about twelve short tunnels on the line, aggregating 16,000 feet in length, one of which is a spiral tunnel 5,460 feet long, with a 985-foot radius. The main tunnel is 47,678 feet long and was first planned to be run on a tangent, but a serious cave 1.6 miles from the north portal, which killed 25 men and filled up 5,900 feet of tunnel, compelled the abandonment of the original line and the adoption of a curved tunnel to pass around the immense, peaty, mud-filled fissure which the heading had tapped.

At the south end Ingersoll-Rand air drills and compressors were used, while in the north end Myers drills and compressors were adopted. Transportation in the tunnel was handled by compressed-air locomotives running on 30-inch gauge tracks. From four to six drills were employed in each heading, mounted on a horizontal bar, which was carried on a carriage, thus necessitating mucking out after firing before drilling could be commenced in the face. For the last thirty months of driving, the

* Trans. A. I. M. E., Vol. XLII, pp. 441–446. Fox, Pro. Inst. C. E., Vol. CLXXIII, pp. 61–83.

average rate of progress in the south heading was 15.8 feet per day, and in the north end, where the driving was much easier, 18.6 feet per day. On the north side, when the heading was in limestone, it was advanced 5,623 feet in six months, or an average rate of 30.8 feet per day.*

The Busk-Ivanhoe tunnel, on the Colorado Midland Railway between Leadville and Glenwood Springs, is 9,394 feet long, and has an altitude of 10,810 feet at Busk and at Ivanhoe 10,944 feet, making it the third highest railway tunnel in the world. It is driven almost the entire distance in metamorphic granite with some softened shear zones which gave considerable trouble in both driving and timbering. The tunnel cost $1,250,000, and thirty men were killed in the progress of the work.†

The Severn tunnel (1873–1887), which is on the line of the Great Western Railway in England, and passes under the estuary of the Severn River, has a length of 4.35 miles and traverses a great variety of strata consisting of conglomerate, limestone, carboniferous beds, sandstone, marl, and sand. The most serious difficulty encountered in driving was the great volume of water coming into the tunnel, not so much from the estuary above as from a huge spring on the land side. Several ineffectual attempts were made to bulkhead this spring, but before the work could be successfully carried on, it was necessary to erect an immense pumping plant with a capacity of 45,000 gallons per minute, but the maximum amount pumped for any considerable period did not exceed 20,000 gallons per minute.‡

The Totley tunnel, on the Dore & Chinley Railway, England, is 3.53 miles in length, and is on the line between Sheffield and Manchester. Work was commenced in 1888 and the completed tunnel was ready for traffic in September, 1893. It is driven almost entirely through carbonaceous black shale which contained some strata of sandstone and grit. The progress of the work was greatly impeded by heavy inrushes of water, some-

* Saunders, Trans. A. I. M. E., Vol. XLII, pp. 446–469. Bonnin, *La Nature*, Paris, 1909, Vol. XXXVII, pp. 147–157.

† *Engineering News*, August 25, 1872.

‡ Vernon-Harcourt, Pro. Inst. C. E., Vol. CXXI, pp. 305–308.

times carrying vast quantities of sand and silt. For a time the discharge from the Padley heading amounted to 5,000 gallons per minute. At first the water was carried out of the tunnel in 12-inch pipes, but as these proved insufficient and liable to clog with sand, the headings were closed up with watertight bulkheads and center drains carried in from the portal. This work took six weeks, during which time the pressure behind one of the dams rose to 155 pounds per square inch.*

The Aspen tunnel on the Union Pacific Railway between Cheyenne and Ogden, although only 5,900 feet in length, is interesting on account of the obstacles encountered in driving, the difficulty of holding back the swelling ground, and the fact that mechanical loading of the broken rock was successfully employed in both headings. The tunnel was driven through carbonaceous shale containing an occasional stratum of yellow sandstone dipping 20° to 30° to the east, while the course of the tunnel was a little south of west. The opening is 22 feet 6 inches high and 17 feet wide in the clear, timbered with 12 by 12-inch timbers with vertical posts capped with a seven-segment circular arch. These timber sets were spaced 2 feet apart, 1 foot apart, or close together, as the weight of the ground demanded. On a portion of the tunnel, walls of solid 12 by 12-inch timbers would not stand the rock pressure, and the timbers were replaced by 12-inch steel I beams, which were sometimes buckled sideways before the concrete filling could be rammed in place.

Small steam shovels of ¾-cubic yard bucket capacity, and operated by compressed air, were employed for loading cars in the headings, and effected a great saving in both time and expense.†

Arthur's Pass tunnel, South Island, New Zealand, sometimes known as the Otiro, is on the line of the New Zealand Government Railway which connects Christchurch on the east with Greymouth on the west coast, and pierces the crest of the Southern Alps for a distance of 5⅜ miles. Work began in May, 1898, and the contract called for the completion of the work in a

* Rickard, Pro. Inst. C. E., Vol. CXVI, pp. 117–138.

† Hardesty, *Engineering News*, March 6, 1902.

period of five years; price $5,000,000. Tunnel haulage was at first attempted with eight-ton benzine locomotives, but they were discarded on account of uncertain action and the annoying fumes, and electric locomotives were substituted.*

PARTIAL LIST OF NOTED RAILROAD TUNNELS†

Name of Tunnel	Country	Length	Summit level	Opened for traffic
		Feet	*Feet*	
Simplon	Switzerland-Italy	65,734	2,313	1906
St. Gothard	Switzerland-Italy	49,212	3,788	1882
Loetschberg	Switzerland	47,685	4,077	1913
Mont Cenis	France-Italy	42,150	4,248	1871
Arlberg	Austria	32,892	4,300	1885
Ricken	Switzerland	28,230	650	1910
Tauern	Austria	28,038	4,020	1909
Ronco	Italy	27,231	....	1888
Tenda	Italy	26,568	3,260	1899
Hauenstein Base	Switzerland	26,400	....	‡
Karawanken	Austria	26,169	2,088	1906
Somport	France-Spain	25,656	....	‡
Jungfrau	Switzerland	23,622	11,220	1912
Borgallo	Italy	23,220	....	1887
Hoosac	United States	23,175	....	1876
Severn	England-Wales	23,028	....	1886
Marianopoli	Sicily	22,453	....	....
Turchino	Italy	21,150	....	1900
Grenchenberg	Switzerland	21,120	1,787	‡
Wocheiner	Austria	20,781	1,761	1909
Mont d'Or	France-Switzerl'nd	20,025	....	‡
Albula	Switzerland	19,290	6,133	1903
Totley	England	18,690	....	1893
Peloritana	Sicily	17,898	....	1885
Gravehals	Norway	17,388	2,844	1909
Puymorens	France-Spain	16,791	....	‡
Standedge	England	16,020	....	1850
Woodhead	England	15,879	....	1845
Bosruck	Austria	15,639	2,405	1906
La Nerthe	France	15,303	....	....
Biblo	Italy	13,907	....	....
Kaiser Wilhelm	Germany	13,767	....	1879
Echarneaux	France	13,620	....	1895
Blaisy	France	13,530	....	....
Cascade	United States	13,413	....	....
Sodbury	England	13,299	....	1903

* Gavin, *Engineering News*, May 9, 1912.

† Abstract from *The Engineer*, November 28, 1913, p. 561–2, with a few additions from other sources.

‡ Under construction 1913–14.

PARTIAL LIST OF NOTED RAILROAD TUNNELS—(*Continued*)

Name of Tunnel	Country	Length	Summit level	Opened for traffic
		Feet	*Feet*	
Credo	France	12,960	....	....
Vizzavona	Corsica	12,894	2,791	1889
Khojak	Baluchistan	12,867	....	1892
Suram	Caucasus	12,810	....	1895
Disley	England	11,598	....	1902
Col de St. Michel	France	11,430	....	1901
Bramhope	England	11,262	....	1849
Festinog	Wales	11,178	....	1879
Cowburn	England	11,106	....	1893
Meudon	France	10,962	....	1900
Giovo	Italy	10,695	1,890	....
Col des Loges	Switzerland	10,560	3,200	....
Cremolina	Italy	10,514	....	....
Stampede	United States	9,850	....	....
Cairasca	Italy	9,840	....	1906
Busk-Ivanhoe	United States	9,394	10,944	....
Caldera	Peru	9,240	15,775	1893
Hauenstein	Switzerland	8,910	....	....
Beacon Hill	China	7,212	....	1910
Transandine	Chile-Argentina	6,933	10,500	1911

The following is a list of some of the more important Japanese tunnels.

Tsudo adit. Ashio Mine, driven September, 1885–October, 1896, 11 feet high, 13 feet wide, and 10,000 feet long. Located on the bank of Watarase River. This tunnel is furnished with double-track electric railway, and has seven shafts, each installed with electric hoist. The mine contains an aggregate length of more than 600,000 feet of levels and winzes.

Omodani Mine. Ono District. Has five levels, aggregating 58,380 feet in length; the longest having a length of 12,110 feet, while the drainage adit is 10,850 feet long.

Yoshioka Mine. Kawakami District. Mine opened by eight levels and crosscuts, totaling 134,281 feet, the main adit being 39,193 feet in length.

Okawamae adit. This adit is for draining the Kusakura Mine, Niigataken, and has a length of 10,000 feet.

*Sosuido tunnel** of Sado Mine, Island of Sado, 11,000 feet long.

*Sosuido adit.** This adit is to drain the Innai Silver Mines, and is 8 feet high, 10 feet wide, and 7,800 feet long.

Nagara Yama tunnel. (No. 1† Lake Biwa Canal, near Kyoto.)

* Sosuido means "Drainage level."

† There are two Lake Biwa Canals, the first executed in 1886–1890, and the second 1909–1911.

Executed in 1886–1890, 14 feet high, 16 feet wide, and 8,040 feet long. Rock of slate and sandstone chiefly.

Nagara Yama tunnel. (No. 2* Lake Biwa Canal, near Kyoto.) Executed in 1909–1911, 13½ feet high, 13 feet wide, and 8,826 feet long. Rock slate chiefly.

Kamuriki Railway tunnel. Shinano District. Executed in 1896–1900. 16½ feet high, 15 feet wide, and the length is 8,712 feet. Hard rock.

Kobotoke Railway tunnel. Kai District. (Imperial Government R.R., in line from Tokyo to Kofu.) Executed in 1897–1900, 16½ feet high, 15 feet wide, and 8,356 feet long. Clay rock chiefly.

Sasago Railway tunnel. Kai District. (Imperial Government R.R. in line from Tokyo to Kofu.) Executed in 1896–1902, 16½ feet high and 15 feet wide. The length is 15,280 feet, being the largest railway tunnel (in one length) completed in Japan. Soft rock.

Ikoma Yama tunnel.† (Kyoto & Nara Electric Ry.) 17 feet 10½ inches high, 22 feet 1½ inches wide, and 11,088 feet long.

Dokuritsu 2^{an}‡ tunnel. Mt. Ari R.R., Formosa. (Just completed.) From Kagi Entrance A to Ari Entrance B, three miles, and the length of the tunnels in that section 1 mile and 23 chains and 77 links. The dimensions of the tunnels are in accordance with the regular construction gauge of the Imperial Government Railways.

Daishi Tsudo. (No. 4 tunnel.) Beshi Copper Mines, Iyo District, 14 feet high, 16 feet wide, and 18,000 feet long. Rock, palæozoic chlorite, and mica schist.

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* There are two Lake Biwa Canals, the first executed in 1886–1890, and the second 1909–1911.

† Yama in this table means altitude or mountain.

‡ 2^{an} means the same as Yama, only in Chinese pronunciation.

CHAPTER III

MODERN MINING AND WATER TUNNELS

RESUMÉ OF DATA

THE following paragraphs contain brief descriptions arranged alphabetically of tunnels and adits visited in the special field work upon which this book is based. In their examination, complete information was obtained, wherever possible, concerning surface and underground equipment, provisions for the safety of the men, the use of explosives, and the methods employed in driving, with regard to efficiency, cost, and other similar data bearing upon the problem. (See Appendix, page 421.) It is impossible, because of lack of space, to reproduce all of this information here, but the following paragraphs convey some briefly idea as to the main features of the different tunnels.

Burleigh tunnel: Silver Plume, Colorado. Purpose, mine drainage and development. Length, 3,000 feet. Cross-section, rectangular, 6 feet wide by 7 feet high. Rock, granite and gneiss. Power, steam. Ventilation, exhaust fan, 10- and 12-inch pipe. Drills, Burleigh drills used in 1869 (first use of machine drills in an American tunnel); Ingersoll-Rand and Leyner drills used in driving last 2,800 feet. Mounting, vertical columns. One shift per day. Two drillers, two helpers, and three muckers per shift. Horse haulage, one-ton cars. Sixty-per-cent gelatine dynamite. No timbering. Average monthly progress, 100 feet. Approximate cost per linear foot, $20. Started in 1869 and driven 200 feet while testing Burleigh drills; extended later to 3,000 feet for mine drainage.

Carter tunnel: Ohio City, Colorado. Purpose, mine drainage and transportation. Length, 6,600 feet. Cross-section, rectangular with arched roof, 5.5 feet wide by 7.5 feet high. Rock, gneiss. Power, hydraulic and hydro-electric. Ventilation, exhaust blower, 10-inch pipe. Two Leyner drills mounted on ver-

tical columns. One drilling and two mucking shifts daily. Two drillers, one helper, and two muckers per shift. Horse haulage, 21-cubic-foot cars. Forty-per-cent and eighty-per-cent gelatine dynamite, 8 pounds per cubic yard. One hundred feet timbered. Approximate cost per linear foot, $10 to $15. Started 1897; on November 1, 1911, had driven 6,550 feet; part of intervening time spent in drifting along laterals; three years shut down entirely, and five years only three men at work.

Catskill Aqueduct: Ulster, Orange, Putnam, and Westchester Counties, and New York City, New York. Length, see list of various tunnels on this project given below. Cross-section, see Figure 5. This aqueduct includes the following tunnels:

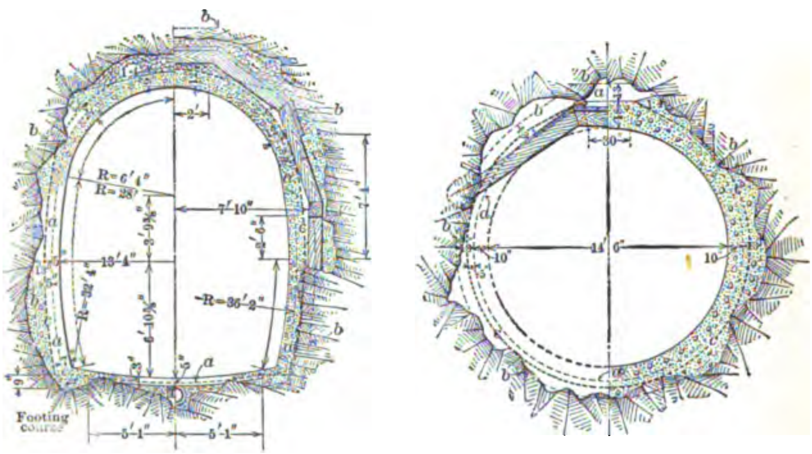

FIG. 5. Cross-sections of typical tunnels, Catskill Aqueduct.

Peak: Length, 3,470 feet. Rock, hard. Started, November, 1908; completed, November, 1909.

Rondout Siphon: Length, 23,608 feet. Cross-section, circular. Rock, Onondaga limestone, Binnewater sandstone, Hudson River shale, Esopus shale, High Falls shale, Shawangunk grit, Hamilton and Marcellus shale, Helderburg limestone. Power, steam. Ventilation, exhaust fan, 14- and 20-inch pipe. Four Ingersoll-Rand drills in each heading. Mounting, vertical column. Two drilling and three mucking shifts per day. Four drillers, four helpers, and ten muckers per shift. Mule haulage,

40-cubic-foot cars. Sixty-per-cent gelatine dynamite, 4 to 5 pounds per cubic yard of heading. Lined with concrete. Average monthly progress per heading, 220 feet. Started, March, 1909; completed, May, 1911.

Bonticou: Length, 6,823 feet. Cross-section, horseshoe. Rock, Hudson River shale. Started, November, 1908; completed, February, 1911.

Wallkill Siphon: Length, 23,391 feet. Cross-section, circular. Rock, Hudson River shale. Power, electricity, purchased. Ventilation, fan, 12- and 14-inch pipe. Four Ingersoll-Rand or Sullivan drills in each heading. Mounting, vertical column. Three shifts per day. Four drillers, four helpers, and eight muckers per shift. Electric haulage, 40-cubic-foot cars. Sixty-per-cent gelatine dynamite, 4.3 to 4.6 pounds per cubic yard of heading. Lined with concrete. Average monthly progress per heading, 300 feet. Started, October, 1909; completed, December, 1910.

Moodna Siphon: Length, 25,200 feet. Cross-section, circular. Rock, hard sandstone, granite, and Hudson River shale. Power, steam. Ventilation, jet of compressed air in 12-inch pipe. Four Ingersoll-Rand drills per heading. Mounting, vertical column. Three shifts per day. Four drillers, four helpers, and ten muckers per shift. Mule haulage, 40-cubic-foot cars. Seventy-five-per-cent gelatine dynamite. Lined with concrete. Average monthly progress per heading, 165 feet. Started, February, 1910; completed, June, 1911.

Hudson Siphon: 1,100 feet below sea level. Length, 3,022 feet. Rock, granite. Started, December, 1910; completed, January, 1912.

Breakneck: Length, 1,054 feet. Cross-section, horseshoe. Rock, granite and gneiss. Started, December, 1910; completed, April, 1911.

Bull Hill: Length, 5,365 feet. Rock, granite. Started, June, 1909; completed, January, 1911.

Garrison: Length, 11,430 feet. Rock, hard gneiss. Started, June, 1907; suspended, November, 1910, to April, 1911; completed, 1912.

Hunters Brook: Length, 6,150 feet. Cross-section, horseshoe. Rock, schist of variable hardness. Started, September, 1909; completed, 1912.

Turkey Mountain: Length, 1,400 feet. Rock, Manhattan schist. Started, October, 1909; completed, December, 1910.

Croton Lake: Length, 2,639 feet. Rock, Manhattan schist and Fordham gneiss. Started, July, 1910; completed, January, 1912.

Croton: Length, 3,000 feet. Rock, Manhattan schist. Started, August, 1909; completed, December, 1911.

Chadeayin: Length, 700 feet. Rock, Manhattan schist. Started, November, 1909; completed, September, 1910.

Millwood: Length, 4,750 feet. Rock, hard gneiss. Started, May, 1910; completed, 1912.

Sarles: Length, 5,230 feet. Rock, hard gneiss and schist. Started, February, 1910; completed, 1912.

Harlem Railroad: Length, 1,100 feet. Rock, hard gneiss and schist. Started, June, 1910; completed, January, 1911.

Reynolds Hill: Length, 3,650 feet. Rock, schist. Started, October, 1910; completed, 1912.

East View: Length, 5,388 feet. Rock, schist. Started, April, 1910; completed, January, 1912.

Elmsford: Length, 2,375 feet. Rock, soft schist. Started, May, 1911; completed, 1912.

Yonkers Siphon: Length, 12,302 feet. Cross-section, circular. Rock, Yonkers gneiss and granite. Power, electrical. No ventilation supplied, except by opening compressed-air line. Four Ingersoll-Rand drills in each heading. Mounting, vertical columns. Two drilling shifts and three mucking shifts per day. Four drillers, four helpers, and eight to twelve muckers per shift. Mule haulage, 40-cubic-foot cars. Sixty-per-cent gelatine dynamite, 4 to 5 pounds per cubic yard of heading. Lined with concrete. Average monthly progress per heading, 155 feet. Started, July, 1910; completed, July, 1911.

Van Cortlandt Siphon: Length, 1,809 feet. Rock, Yonkers gneiss. Started, July, 1910; completed, September, 1911.

City tunnel: Length, 18.11 miles. Rock, Fordham gneiss and Manhattan schist. Started, December, 1911; completed, 1914.

Central tunnel: Idaho Springs, Colorado. Purpose, mine drainage and transportation. Length, 9,000 feet. Cross-section, rectangular. Two thousand five hundred feet driven 12 feet wide by 8 feet high; the remainder 5 feet wide by 7 feet high. Rock, Idaho Springs gneiss. Power, steam. Ventilation, exhaust with blower through 19-inch pipe. Two Leyner drills in the heading. Mounting, horizontal bar. One shift per day. Two drillers, two helpers, and four muckers per shift. Horse haulage, 30-cubic-foot cars. Forty-per-cent gelatine dynamite, 5 to 7 pounds per cubic yard of heading. One hundred feet timbered. Average monthly progress in the heading, 200 feet.

Coronado tunnel: Metcalf, Arizona. Purpose, mine development and transportation. Length, 6,300 feet. Cross-section, square, 9 by 9 feet. Rock, granite and porphyry. Power, steam with crude oil as fuel. Ventilation, blow and exhaust with pressure blower through a 12-inch pipe. Ingersoll-Rand and Sullivan drills were used in the first half of the tunnel, Leyner-Ingersoll drills were used in the last half. Three shifts per day. Two and three drillers, one helper, and four to six muckers per shift. Mule haulage, "one-ton" cars. Sixty-per-cent and 100-per-cent gelatine dynamite. Average monthly progress, 415 feet. Average cost per linear foot, $22.64. (See page 329.) Started, June, 1912; completed, August, 1913.

Gold Links tunnel: Ohio City, Colorado. Purpose, mine drainage and transportation. Length, 3,900 feet. Cross-section, rectangular with arched roof, 6 feet wide by 8 feet high. Rock, gneiss, intruded granite, porphyry. Ventilation, exhaust with fan through 15-inch pipe. One Ingersoll-Rand drill. Mounting, vertical column. Two shifts per day. One driller, one helper, and two or three muckers per shift. Horse haulage, 25-cubic-foot cars. Forty-per-cent gelatine dynamite, 5 to 6 pounds per cubic yard of heading. Two hundred feet timbered. Average monthly progress, 200 feet. Approximate cost per linear foot, not including permanent equipment, $19. Started, May, 1906; driven intermittently; completed, December, 1912.

Gunnison tunnel: Montrose, Colorado. Purpose, irrigation.

Length, 30,645 feet. Cross-section, horseshoe, 10 feet wide, 12.5 feet high. Rock, chiefly metamorphosed granite, with some water-bearing clay and gravel, some hard black shale, and a zone of faulted and broken material. Power, steam. Ventilation, blow and exhaust with blower through 15-inch pipe. Four Sullivan drills per heading (Leyner drills also tried). Mounting, vertical column for Sullivan drills; horizontal bar for Leyner drills. Three shifts per day. Four drillers, four helpers, and five to eight muckers per shift. Electric haulage, 35- and 54-cubic-foot cars. Sixty- and 40-per-cent gelatine dynamite. 5.5 pounds per cubic yard of heading. Fourteen thousand five hundred feet timbered. Average monthly progress per heading, 250 feet. Cost per linear foot of tunnel, $70.66. Started, January, 1905; completed, July, 1909.

Laramie-Poudre tunnel: Larimer County, Colorado. Purpose, irrigation. Length, 11,300 feet. Cross-section, rectangular, 9.5 feet wide by 7.5 feet high. Rock, close-grained granite. Power, hydraulic and hydro-electric. Ventilation, exhaust with blower through 14-inch and 15-inch pipe. Three Leyner drills in the heading. Mounting, horizontal bar. Three shifts per day. Three drillers, two helpers, and six muckers per shift. Mule haulage, 16-cubic-foot cars. Sixty- and 100-per-cent. gelatine dynamite, 3.9 to 4.9 pounds per cubic yard of heading. Six hundred and thirty feet timbered. Average monthly progress per heading, 509 feet. Cost per linear foot of tunnel, $39.54. Started, December, 1909; completed, July, 1911.

Lausanne tunnel: Mauch Chunk, Pennsylvania. Purpose, mine drainage. Length, 20,000 feet. Cross-section, arched roof, 12 feet wide by 8 feet high. Rock, shale, conglomerate, slate, and anthracite coal. Power, steam. Ventilation, blow with fan through two 16-inch pipes. Two Ingersoll-Rand drills in the heading. Mounting, vertical columns. Three shifts per day. Two drillers, two helpers, and four to five muckers per shift. Electric haulage, 78-cubic-foot cars. Sixty-per-cent gelatine dynamite. Average monthly progress per heading, 340 feet. Cost per linear foot of tunnel, $19. Started, July, 1906; completed, February, 1912.

Los Angeles Aqueduct: Location, Inyo, Kern, and Los Angeles Counties, California. Purpose, water supply, power, and irrigation. Cross-section, see Figure 6.

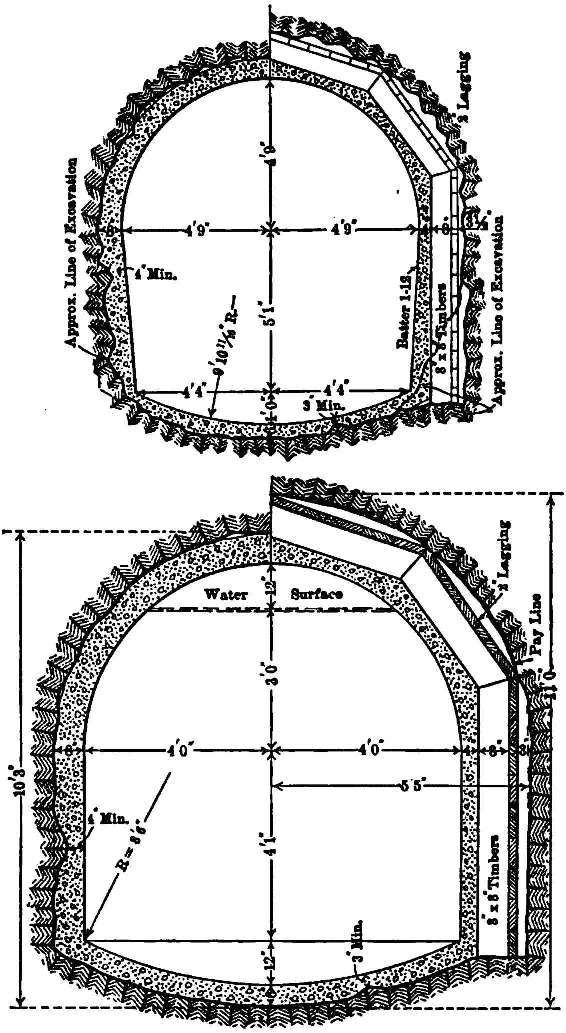

FIG. 6. Cross-sections of typical tunnels, Los Angeles Aqueduct.

Little Lake and Grapevine Divisions: Power, electricity, purchased from separate plant owned by the Aqueduct. Ventila-

tion, blow and exhaust with pressure blower through 12-inch pipe. Two Leyner drills per heading. Mounting, horizontal bar. One and two shifts on Little Lake Division; two shifts per day on Grapevine Division. Two drillers, two helpers, and five muckers per shift. Mule and electric haulage on Little Lake Division; electric haulage on Grapevine Division, 32-cubic-foot cars both Divisions. Forty-per-cent gelatine dynamite, 4½ pounds per cubic yard of heading, Grapevine Division; 14,745 feet timbered on Little Lake Division; 1,500 feet timbered on Grapevine Division. Started, 1909; completed, 1913.

Tunnel 1B: Length, 1,918 feet. Rock, medium granite. Started, June, 1909; completed, December, 1909.

Tunnel 2: Length, 1,739 feet. Rock, medium granite, very wet. Started, May, 1909; completed, September, 1909.

Tunnel 2A: Length, 1,322 feet. Rock, medium granite. Started, May, 1909; completed, September, 1909.

Tunnel 3: Length, 4,044 feet. Rock, north heading, medium granite; south heading, variable granite, with pockets of CO_2 gas. Started, March, 1909; completed, July, 1911.

Tunnel 4: Length, 2,033 feet. Rock, medium to hard granite. Started, February, 1909; completed, November, 1909.

Tunnel 5: Length, 1,178 feet. Rock, medium to hard granite. Started, February, 1909; completed, July, 1909.

Tunnel 6: Length, 411 feet. Rock, medium granite. Started, February, 1909; completed, May, 1909.

Tunnel 7: Length, 3,596 feet. Rock, variable, soft, and swelling in parts. Started, March, 1909; completed, July, 1911.

Tunnel 8: Length, 2,560 feet. Rock, medium to hard, swelling in parts. Started, November, 1909; completed, August, 1911.

Tunnel 9: Length, 3,506 feet. Rock, medium to hard granite. Started, November, 1909; completed, February, 1911.

Tunnel 10: Length, 5,755 feet. Rock, medium granite. Started, December, 1909; completed, August, 1911.

Tunnel 10A: Length, 5,961 feet. Rock, medium to hard granite. Started, March, 1910; completed, December, 1911.

GRAPEVINE DIVISION:

Tunnel 12: Length, 4,900 feet. Rock, hard granite. Started, July, 1909; completed, May, 1911.

Tunnel 13: Length, 1,958 feet. Rock, hard granite. Started, May, 1909; completed, April, 1910.

Tunnel 14: Length, 859 feet. Rock, hard granite. Started, April, 1909; completed, February, 1910.

Tunnel 15: Length, 895 feet. Rock, hard granite. Started, May, 1909; completed, December, 1909.

Tunnel 16: Length, 2,723 feet. Rock, hard granite. Started, April, 1909; completed, February, 1910.

Tunnel 17: Length, 3,022 feet. Rock, hard granite. Started, March, 1909; completed, November, 1910.

Tunnel 17½: Length, 1,364 feet. Rock, hard granite. Started, January, 1910; completed, November, 1910.

Tunnel 17 A: Length, 5,330 feet. Rock, hard granite. Started, January, 1910; completed, February, 1912.

Tunnel 17 B: Length, 9,220 feet. Started, March, 1910; completed, 1912.

ELIZABETH LAKE DIVISION:

Elizabeth Lake tunnel: Length, 26,860 feet. Cross-section, rectangular with arched roof, 12.3 feet high by 12.75 feet wide. Rock, medium to hard granite. Power, electricity. Ventilation, blow and exhaust with blower through 18-inch pipe. Three Leyner drills in each heading. Mounting, horizontal bar. Three shifts per day. Three drillers, three helpers, and nine muckers per shift. Electric haulage, 32-cubic-foot cars. Forty-per-cent gelatine dynamite, 5 to 6 pounds per cubic yard of heading. Sixteen thousand four hundred feet timbered. Average monthly progress per heading, 350 feet. Cost per linear foot of tunnel, $40.50. Started, October, 1907; completed, February, 1911.

Lucania tunnel: Idaho Springs, Colorado. Purpose, mine development and transportation. Length, 6,385 feet. Cross-section, 8 feet square. Rock, hard granite. Power, purchased electricity. Ventilation, exhaust with blower through 18-inch and 19-inch pipe. Three Leyner drills in the heading. Mount-

ing, vertical column. One shift per day. Three drillers, two helpers, and three muckers per shift. Horse haulage, 22-cubic-foot cars. Fifty-per-cent gelatine dynamite, 8 to 9 pounds per cubic yard of heading. No timbering. Average monthly progress, 125 feet. Cost per linear foot of tunnel, $23.06. Started, 1901; driven intermittently; completed, 1911.

Marshall-Russell tunnel: Empire, Colorado. Purpose, mine drainage, development, mining, and transportation. Length, 6,400 feet. Cross-section, rectangular, 8 feet wide by 9 feet high. Rock, granite and gneiss. Power, purchased electricity with auxiliary hydraulic plant. Ventilation, exhaust with fan through 12-inch and 13-inch pipe. Two Leyner drills in the heading. Mounting, vertical column. One shift per day. Two drillers, two helpers, and four muckers per shift. Horse haulage, 28- and 25-cubic-foot cars. Forty- and 80-per-cent gelatine dynamite. One hundred and fifty feet timbered. Average monthly progress, 160 feet. Cost per linear foot of tunnel, $18.88. Started, 1901; driven intermittently; completed, 1911.

Mission tunnel: Santa Barbara, California. Purpose, water supply. Length, 19,560 feet. Cross-section, trapezoid, 4.5 feet wide at the top, 6 feet wide at the base, and 7 feet high. Rock, shale, slate, and hard sandstone. Power, purchased electricity. Ventilation, blow and exhaust with blower through 10-inch pipe. One Leyner drill in the heading. Mounting, horizontal bar. Three shifts per day. One driller, one helper, and four muckers per shift. Electrical haulage, 22-cubic-foot cars. Forty- and 60-per-cent gelatine dynamite, 6 to 8 pounds per cubic yard of heading. Five hundred and sixty feet timbered. Average monthly progress, 210 feet. Cost per linear foot of tunnel, $19.91. Completed, 1912.

Newhouse tunnel: Idaho Springs, Colorado. Purpose, drainage and transportation. Length, 22,000 feet. Cross-section, 8 feet square. Rock, Idaho Springs gneiss. Power, purchased electricity. Ventilation, exhaust with pressure blower through 18-inch pipe. Two and three Leyner drills in the heading. Mounting, horizontal bar and vertical column at different times. One and two drill shifts per day. Two and three drillers, two

helpers, and three muckers per shift. Electric haulage, 57- and 35-cubic-foot cars. Forty- and 100-per-cent gelatine dynamite. One thousand feet timbered. Started, 1893; driven intermittently; completed, November, 1910.

Nisqually tunnel: Alder, Washington. Purpose, hydro-electric power for City of Tacoma. Length, 10,000 feet. Cross-section, rectangular with arched roof, 9½ feet wide by 11 feet high. Rock, rhyolite. Power, hydraulic and hydro-electric. Ventilation, exhaust with fan through 14-inch pipe. Two Ingersoll-Rand drills at the headworks end, two Leyner drills at the discharge end. Mounting, horizontal bar. Two drilling shifts and three mucking shifts per day. Two drillers, two helpers, and four muckers per shift. Electric haulage, 27-cubic-foot cars. Forty-per-cent gelatine dynamite. Practically no timbering. Average monthly progress per heading, 300 feet. Approximate cost per linear foot of tunnel, not including permanent equipment, $15 to $20. Started, 1910; completed, 1912.

Ontario tunnel: Park City, Utah. Purpose, mine drainage. Length, 24,000 feet. Cross-section, trapezoid, 5 feet wide at the base, 4 feet wide at the top, 7½ feet high. Rock, porphyry, granite, quartzite, and limestone. Started, July 25, 1908; suspended for several periods of from one to fourteen months; still unfinished.

Rawley tunnel: Bonanza, Colorado. Purpose, mine drainage and development. Length, 6,235 feet. Cross-section, trapezoid, 8 feet wide at the base, 7 feet wide at the top, 7 feet high. Rock, andesite. Power, steam, wood fuel. Ventilation, exhaust with pressure blower through 12-inch and 13-inch pipe. Two Leyner drills in the heading. Mounting, horizontal bar. Two and three shifts per day. Two drillers, two helpers, and three muckers per shift. Horse haulage, 17-cubic-foot cars. Forty- and 60-per-cent gelatine dynamite, 6 pounds per cubic yard of heading. One thousand six hundred and eighteen feet timbered. Average monthly progress, 350 feet. Cost per linear foot of tunnel, $19.88. Started, May, 1911; completed, October, 1912.

Raymond tunnel: Ohio City, Colorado. Purpose, mine drainage and development. Length, 3,200 feet. Cross-section, 9 feet

square. Rock, granite and gneiss. Power, steam. Ventilation, blow and exhaust with blower through 14-inch pipe. Three Leyner drills in the heading. Mounting, horizontal bar. One shift per day. Three drillers, two helpers, and two to three muckers per shift. Horse haulage, 32-cubic-foot cars. Forty- and 60-per-cent gelatine dynamite, 3 to 4 pounds per cubic yard of heading. One hundred feet timbered. Average monthly

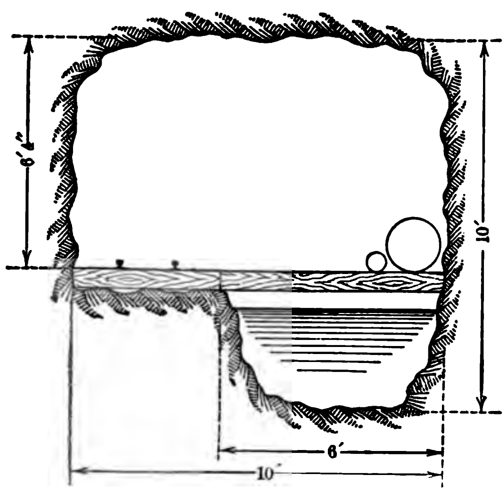

FIG. 7. Cross-section, Roosevelt Tunnel.

progress, 200 feet. Approximate cost per linear foot of tunnel, $15. Started, 1903; driven intermittently; completed, 1912.

Roosevelt tunnel: Cripple Creek, Colorado. Purpose, mine drainage. Length, 15,700 feet. Cross-section, see Figure 7. Rock, Pike's Peak granite. Power, purchased electricity. Ventilation, exhaust with pressure blower through 16-inch and 17-inch pipe. Two and three Leyner drills in the heading. Mounting, horizontal bar. Three shifts per day. Three drillers, two helpers, and four muckers per shift. Mule haulage, 16-cubic-foot cars. Sixty- and 100-per-cent gelatine dynamite. No timbering. Average monthly progress per heading, 285 feet. Cost per linear foot of tunnel, $27.27. Started, February, 1908; completed, November, 1910.

Shepard's Pass tunnel: Oakland, California. Purpose, electric railway. Length, 3,000 feet. Rock, shale. Power, electricity. Ventilation, fan. Three or four Ingersoll-Rand drills per heading. Horizontal bar mounting. One shift per day. Three to four drillers and helpers, four to six muckers (per heading) per shift. Electric haulage. Forty-per-cent gelatine dynamite. All timbered, ground very heavy. Average monthly progress, 160 to 175 feet. Started, 1911; completed, 1913.

Siwatch tunnel: Leadville, Colorado. Purpose, development. Length, 5,000 feet. Cross-section, rectangular, 6 feet wide by 7.5 feet high. Rock, granite. Power, purchased electricity. Ventilation, exhaust with pressure blower through 10-inch pipe. Two Waugh stoping drills in the heading. Mounting, horizontal bar. Two shifts per day. Two drillers, no helpers, and two to three muckers per shift. Electric haulage, 33-cubic-foot cars. Forty-per-cent gelatine dynamite. Six hundred feet timbered. Driven intermittently; not yet completed.

Snake Creek tunnel: Heber, Utah. Purpose, mine drainage and development. Length, 14,000 feet. Cross-section, rectangular, 9.5 feet wide by 6.5 feet high. Rock, diabase. Power, purchased electricity. Ventilation, exhaust with pressure blower through 16-inch pipe. Two Sullivan drills in the heading. Mounting, horizontal bar. Two shifts per day. Two drillers, two helpers, and three muckers per shift. Horse haulage, 20-cubic-foot cars. Forty- and 60-per-cent gelatine dynamite, 7 pounds per cubic yard of heading. Three hundred and fifty feet timbered. Average monthly progress, 250 feet. Started, May, 1910; driven intermittently; not yet completed.

Stilwell tunnel: Telluride, Colorado. Purpose, mine drainage and development. Length, 2,600 feet. Cross-section, 7 feet square. Rock, conglomerate and andesite. Power, purchased electricity. Ventilation, exhaust with fan through 10-inch pipe. Two Ingersoll-Sergeant drills in the heading. Mounting, vertical column. One shift per day. Two drillers, two helpers, and three muckers per shift. Horse haulage, 22-cubic-foot cars. Forty-per-cent gelatine dynamite, 8 to 10 pounds per cubic yard of heading.

No timbering. Average monthly progress, 150 feet. Cost per linear foot of tunnel, $23.38. Started, 1901; driven intermittently; completed, 1906.

Strawberry tunnel: Wasatch County, Utah. Purpose, irrigation. Length, 19,100 feet. Cross-section, arched roof, 8 feet wide, 9½ feet high. Rock, shale and sandstone. Power, electric. Ventilation, exhaust with pressure blower through 14-inch pipe. Two Sullivan drills in the heading. Mounting, vertical column. Three shifts per day. Two drillers, two helpers, and six muckers per shift. Electric haulage, 47-cubic-foot cars. Forty-per-cent gelatine dynamite, 5 to 6 pounds per cubic yard heading. Two thousand five hundred feet timbered. Average monthly progress, 300 feet. Cost per linear foot of tunnel, $36.78. Started, 1906; completed, 1912.

Utah Metals tunnel: Tooele, Utah. Purpose, transportation. Length, 11,780 feet. Cross-section, rectangular, 10 feet wide by 8 feet high. Rock, quartzite. Power, hydraulic. Ventilation, exhaust with fan through 12-inch pipe. Two Ingersoll-Rand drills in the heading. Mounting, horizontal bar. Two shifts per day. Two drillers, two helpers, and four muckers per shift. Electric haulage, 32-cubic-foot cars. Forty- and 60-per-cent gelatine dynamite, 4 to 5 pounds per cubic yard of heading. Five hundred feet timbered. Average monthly progress, 250 feet. Approximate cost per linear foot of tunnel, $15. Started, 1906; driven intermittently; not yet completed.

Yak tunnel: Leadville, Colorado. Purpose, transportation and development. Length, 23,800 feet. Cross-section, 7 feet square. Rock, sandstone, limestone, shale, porphyry, and granite. Power, electric. No ventilation supplied, except by opening compressed-air line. Two Ingersoll-Rand drills in the heading. Mounting, horizontal bar. Three shifts per day. Two drillers, two helpers, and two muckers per shift. Electric haulage, 30-cubic-foot cars. Forty per cent. gelatine dynamite, 4 to 5 pounds per cubic yard of heading. Eight thousand feet timbered. Average monthly progress, 200 feet. Approximate cost per linear foot of tunnel, $20. Started, 1886; driven intermittently; completed, 1910.

MODERN TUNNELS DESCRIBED IN ENGINEERING MAGAZINES

The following tables are comparable with those above, and give practically similar information concerning certain tunnels which were not examined in the field, but which are quite fully described in engineering periodicals. Although the information contained in these various accounts is, perhaps, somewhat less complete than similar data obtained at other tunnels actually visited, nevertheless it is generally sufficient in each case to convey a good idea of the main features of the work done.

Buffalo Water Works tunnel: Buffalo, New York. Purpose, water supply. Length, 6,575 feet. Cross-section, nearly rectangular, 15 feet wide by 15½ feet high. Rock, limestone. Power, steam. Ventilation, tunnel driven under compressed air, no ventilation used. Four Ingersoll-Sergeant drills in the heading. Mounting, vertical column. Three shifts per day. Four drillers, four helpers, and ten muckers per shift. Electric haulage, 27-cubic-foot cars. Sixty-per-cent gelatine dynamite, 4.8 pounds per cubic yard of heading. Average monthly progress, 235 feet. Started, July, 1907; completed, April, 1910. Reference, *Engineering Record*, June 25, 1910, page 802.

Chipeta adit: Ouray, Colorado. Purpose, mine development. Length, 2,000 feet. Cross-section, 7.5 feet square. Power, steam. No ventilation supplied except by opening compressed-air line. Two Ingersoll-Rand drills in the heading. Mounting, horizontal bar. Two shifts per day. Two drillers, one helper, and four muckers per shift. Mule haulage, 20-cubic-foot cars. Five to 6 pounds of explosive per cubic yard of heading. One hundred and fifteen feet timbered. Average monthly progress per heading, 340 feet. Approximate cost per linear foot of tunnel, not including permanent equipment, $12. Started, August, 1907; completed, March, 1908. Reference, *Mining and Scientific Press*, July 11, 1908, page 60.

Cornelius Gap tunnel: Near Portland, Oregon. Purpose, electric railway. Cross-section, arched roof, 17.5 feet wide by 22.5

feet high. Length, 4,100 feet. Rock, basalt. Reference, *Engineering News*, June 29, 1911, page 783.

Fort Williams Water tunnel: Fort Williams, Ontario. Purpose, water supply. Length, 4,820 feet. Cross-section, rectangular with arched roof, 5 feet wide, 6.5 feet high. Rock, basalt. Power, electric. Ventilation, blow with fan through 15-inch pipe. One Ingersoll-Rand drill in heading. Mounting, vertical column. Two and three shifts per day. One driller, one helper, and three muckers per shift. Eighteen-cubic-foot cars. Forty-per cent. gelatine dynamite, 5 to 10 pounds per cubic yard of heading. Lined with concrete. Average monthly progress per heading, 85 feet. Cost per linear foot of tunnel, $27.89. Started, May, 1907; completed, May, 1909. Reference, *Engineering and Contracting*, May 25, 1910, page 472.

Grand Central tunnel: New York City. Purpose, sewer. Length, 3,000 feet. Cross-section, circular, 8 feet in diameter. Rock, gneiss. No ventilation supplied, except by opening compressed-air line. Two and three Ingersoll-Rand and Sullivan drills in the heading. Mounting, vertical column. One shift per day. Two and three drillers, two and three helpers, and two muckers per shift. Used a ½-cubic-foot bucket on a flat car. Started, 1907; completed, 1908. Reference, *Engineering Record*, April 11, 1908, page 496.

Joker tunnel: Red Mountain, Colorado. Purpose, mine drainage and development. Length, 5,055 feet. Cross-section, rectangular, 12 feet wide, 11 feet high. Power, steam. Ventilation, exhaust with fan through 15-inch pipe. Two and three Leyner drills in the heading. Mounting, vertical column. One drill shift and two mucking shifts per day. Two and three drillers, two helpers, and four muckers per shift. Mule haulage, 30-cubic-foot cars. Practically all timbered. Average monthly progress, 215 feet. Completed, 1907. Reference, *Mines and Minerals*, May, 1907, page 470.

Kellogg tunnel: Wardner, Idaho. Purpose, mine development. Length, 9,000 feet. Cross-section, arched roof, 9 feet wide and 11 feet high. Rock, quartzite. Reference, *Mines and Minerals*, October, 1901, page 122.

Mount Royal tunnel: Montreal, Canada. Purpose, railroad. Length, 3.25 miles. Cross-section, rectangular with arched roof, during construction 30.5 feet wide and 21.25 feet high, when completed will be twin tubes each 13.5 feet wide and 14 feet high, separated by an 18-inch wall of concrete. Rock, limestone and volcanic breccia. Power, purchased electricity. Ventilation, pressure blower. Three or four Sullivan water drills per heading. Mounting, horizontal bar and special drill carriage. Three shifts per day; four drillers, four helpers, and six muckers per shift. Electric haulage. Sixty-per-cent gelatine dynamite. Average progress in No. 1 heading, first eight months, 351 feet. References, *Engineering and Mining Journal*, July 26, 1913, pages 147-49; *Mine and Quarry*, August 1913, pages 730-39.

Northwest Water tunnel: Chicago, Illinois. Purpose, water supply. Length, 21,180 feet. Cross-section, horseshoe, area equivalent to 14-foot circle. Rock, limestone. No ventilation supplied, except by opening compressed-air line. Four Ingersoll-Rand drills in the heading. Mounting, vertical column. Two shifts per day. Four drillers, four helpers, and six muckers per shift. Mule haulage, 22-cubic-foot cars. Average monthly progress per heading, 400 feet. Reference, *Engineering Record*, August 7, 1909, page 144.

Ophelia tunnel: Cripple Creek, Colorado. Purpose, mine drainage and development. Length, 8,500 feet. Cross-section, 9 feet square. Rock, granite and breccia. Power, steam. Ventilation, blow with pressure blower through 15-inch pipe. Two Sullivan drills in the heading. Mounting, vertical column. Three shifts per day. Two drillers, two helpers, and three muckers per shift. Compressed air haulage. Average monthly progress, 350 feet. Started, 1905; completed, 1907. Reference, *Mine and Quarry*, May, 1907, page 118.

Roger's Pass tunnel: Between Ross Peak and Beaver Mouth, British Columbia. Purpose, railroad. Length, 25,900 feet. Cross-section, rectangular with arched roof. Will be driven from a center heading 14 feet wide and 8 feet high and from an auxiliary heading 30-50 feet to one side of the main heading, 8 feet wide and 7 feet high. Rock, shale and quartzite. Power, steam.

Ventilation, pressure blower. Three Ingersoll-Leyner drills per heading. Horizontal bar mounting. Three shifts per day. Three drillers, two helpers, and four to six muckers per shift. Mule haulage. Work on portal excavation started August, 1913. Reference, private communication to the authors.

Second Raton Hill tunnel: Raton Pass, Colorado. Purpose, railway. Length, 2,790 feet. Cross-section, horseshoe, 22 feet wide and 29 feet high. Rock, shale, sandstone, and a 3-foot bed of soft coal. Reference, *Engineering Record*, April 4, 1908, page 461.

"Spiral" tunnels: Selkirk Mountain, British Columbia. Purpose, railway. Length, No. 1, 3,200 feet; No. 2, 2,890 feet. Cross-section, arched roof, 22 feet wide, 27 feet high. Rock, limestone. Power, steam. Six and eight Ingersoll-Rand drills in the heading. Mounting, vertical column. Two shifts per day. Six and eight drillers, six and eight helpers per shift. A Marion shovel operated by compressed air used for mucking. Horse haulage, 108-cubic-foot cars. All timbered. Average monthly progress per heading, 105 feet. Started, January, 1908; completed, June, 1909. References, *Engineering News*, November 10, 1910, page 512; *Compressed Air Magazine*, February, 1911, page 5,931.

CHAPTER IV

CHOICE OF POWER FOR TUNNEL WORK

SOURCES OF POWER

WHILE the power for tunnel operations may be obtained from various sources, in general practice at present it is produced primarily from either steam or flowing water. Although, as far as could be ascertained, the gas-producer used in connection with internal-combustion engines has been installed at but one tunnel, nevertheless it offers a third possibility as a source of power which will have to be considered more and more seriously in the design of future plants. It is true that in the early stages of its development, when the principles governing its design, construction, and operation were not well understood, the gas-producer was not reliable and acquired a bad reputation among tunnel men, a situation augmented perhaps by the extravagant claims of manufacturers or the overzealousness of salesmen. But within the last few years, as its principles have become better known through study and experiment, the gas-producer has developed rapidly—so rapidly, in fact, that few people realize that it is to-day as reliable and rugged a piece of apparatus as an ordinary boiler, or that its consumption of fuel is only one-third as great, or that the labor to operate it need not be one whit more skilled. It is true that gasoline engines are occasionally used to furnish power in tunnel operations, but they have been confined either to temporary plants or to small and isolated units of machinery. In localities where petroleum is cheap, it is probable that an oil engine of the Diesel type, with its wonderful fuel economy, may be found the cheapest means of producing power. Electricity, especially where it is used at tunnel plants to operate prime moving machinery, is sometimes considered a source of power; but since the current so employed has to be generated elsewhere, usually from steam or water, but possibly from pro-

ducer gas, petroleum, or gasoline, electricity is merely a convenient form for transmitting power instead of a source.

PRODUCTION OF POWER

WATER-POWER.—In tunneling the machines most frequently employed for the utilization of water-power are of the impulse type, similar to the Pelton wheel, illustrated in Figure 8. Such

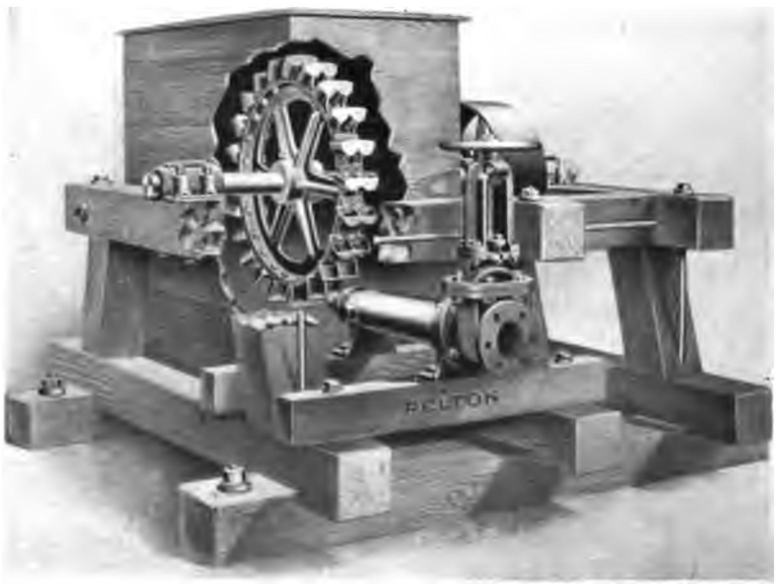

FIG. 8. Standard Pelton wheel.

a wheel is driven by the force of a stream of water issuing from a nozle, acting against vanes or buckets on the circumference of the wheel, and is well adapted for use with a relatively small volume of water under high head. The efficiency of the machine is dependent upon the way the vanes or buckets reverse the direction of the water discharged upon them; hence they usually conform to a curve which is very carefully designed to avoid loss of power through eddies and friction as the water strikes the vane. There may be more than one nozle in order to obtain greater power, or, if high rotative speed is desired, a small wheel

with multiple nozles may be substituted for a large one. In order to obtain the best results, the peripheral speed of the cups or vanes should be between 42 and 48 per cent of the speed of the water issuing from the nozle. Impulse wheels are manufactured in many different designs, sizes, and speeds, adapted for working under widely diverse conditions. Those observed at the different tunnels examined were, as far as could be learned, giving very satisfactory service.

The turbine wheel, in which the force of the water is made to act through suitable guides upon all the vanes or blades simultaneously, affords another means of utilizing water-power and may be designed for either high or low heads. Its use is limited, however, especially with high heads, to localities where clear water is available (as, for example, at Niagara Falls) because of the destructive abrasive action of sand and grit upon the guides. With low heads this action is not so marked. Since the source of water-power in the vicinity of tunnels and adits is in most cases to be found in streams furnishing high heads and which at certain seasons of the year carry large amounts of sediment, the use of turbine wheels for such plants is prohibitive unless large settling basins can be provided.

The hydraulic compressor, converting the energy of water directly into compressed air, offers a third method for utilizing water-power. The earliest type operates upon the principle of the hydraulic ram, in which a column of water is allowed to acquire velocity and is then suddenly checked, developing intermittently for a short space of time pressure much greater than that due to the head of the column of water. This pressure is employed in compressing air. Sommeiller in about 1860 designed a machine of this type for use at the Mt. Cenis tunnel. Such compressors require rather high heads and have low efficiency. Although conditions might be such as to make the use of compressors of this type desirable, the water-power they require can generally be utilized more advantageously in some other manner.

The hydraulic compressor recently developed by C. H. Taylor, introducing air into a column of water and compressing it as they fall together to the bottom of a shaft where the air is separated

and collected, is very efficient and requires only a small amount of attention, although the cost of construction prohibits its use except for installations much larger than those ordinarily required for tunnel work. The latest installation of this system, which was completed in June, 1910, is situated at Ragged Chutes,

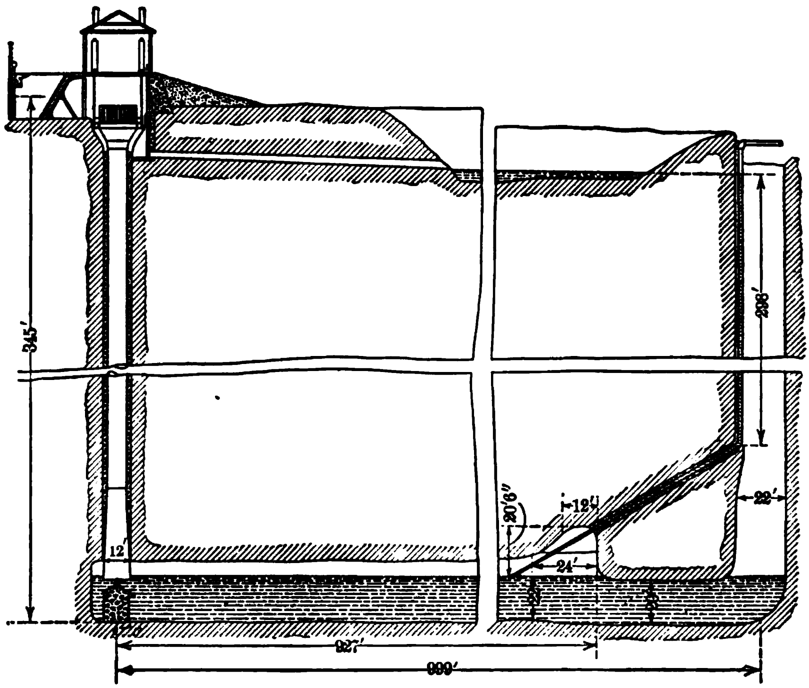

FIG. 9. Diagrammatic section through Taylor hydraulic compressor at Cobalt.

on the Montreal River, and supplies air to the mining district near Cobalt, Ontario.

At this plant, a concrete dam diverts water from the river, above the rapids, to the tops of two circular shafts 8½ feet in diameter, where, by means of suitable apparatus, a large quantity of air is introduced into the water in the form of bubbles. The mixed water and air descend the shafts (350 feet in depth) and start through a passage 1,000 feet long. The passage as shown in Figure 9 is so designed that the compressed air is permitted to rise to the surface of the water and is collected,

partly along the top of the passage and partly in a large collecting chamber which has been excavated near the end of the passage. The waste water then rises 298 feet through a shaft 22 feet in diameter and is discharged into the river below the rapids. The air is drawn from the top of the chamber at a pressure of 120 pounds to the square inch and is transmitted by a 20-inch main to the mines nine miles distant. The capacity of the plant is the compression of 40,000 cubic feet of free air per minute to 120 pounds per square inch.

The familiar overshot, breast, and undershot wheels are not used to drive machinery for tunnel work, because of their large size for the amount of power developed, as well as the trouble of their maintenance. The overshot wheel utilizes the weight of the water, chiefly, and is best suited for low heads. Its efficiency is greatest when enough water is supplied to fill the buckets completely. The breast wheel utilizes both the weight and the velocity of the water, and its efficiency is less, though it can be used with even lower heads of water than the overshot wheel. The undershot wheel uses only the velocity of the water, and has the least efficiency of the three types, but it requires practically no head. Its efficiency is at a maximum when the water is confined laterally.

The following table, which is based upon actual results, shows the efficiency of different types of water motors:

PERCENTAGE OF THEORETICAL HORSE-POWER REALIZED BY VARIOUS WATER MOTORS

Impulse wheels	70–85%
Turbine wheels	75–85
Overshot wheels	60–65
Breast wheels	50–60
Undershot wheels	30–50

Results obtained at the testing flume of the Holyoke (Mass.) Water Company, whose tests are taken as standard by American engineers, show efficiencies for turbine wheels under favorable conditions of over 90 per cent,* but this is unusual, the figures

* Trans. A. S. C. E., Vol. XLIV (1910), p. 322.

above being much nearer ordinary practice. The efficiency of hydraulic compressors of the ram type is about 30 to 40 per cent, while the Taylor compressor at Cobalt is said to utilize at least 75 per cent of the theoretical power of the water.

STEAM.—Steam engines are of two types, reciprocating and turbine. In the reciprocating engine, power is developed by the pressure and expansion of steam in a cylinder acting against a moving piston. Such engines may be either simple or compound, both forms being used in tunnel plants. In the former, the total expansion of the steam and consequent reduction of pressure take place in one cylinder, while in the latter only a portion of the expansion takes place in the first cylinder, and the steam, under somewhat reduced pressure, is expanded further in a second cylinder, necessarily larger because of the lower pressure of the steam.

The steam turbine is similar in principle to the water-wheel, except that steam instead of water is the motive fluid. Owing to their economy, small size per unit of power, and freedom from vibration, their use is steadily increasing on both land and sea. Modern steam turbines in sizes of 250 to 500 horse-power, with a steam pressure of 150 pounds and a 28-inch vacuum, will develop a kilowatt-hour with a consumption of from 18 to 20 pounds of steam. A recently published series of shop tests on a 300-kilowatt Swiss condensing turbine showed that with 112½ pounds of steam and a 96.6 per cent. vacuum it was able to produce a kilowatt-hour with 16.1 pounds of steam. The difficulty of reducing the high rotative speed of the turbine engine down to the restricted speed of reciprocating machinery has prevented, until recently, the use of turbine engines in tunnel installations; but, with the advent of the turbo-compressor, we may expect to see them dividing the field, or, perhaps, entirely displacing the cumbersome reciprocating plants now in vogue.

INTERNAL COMBUSTION.—Internal-combustion engines develop power from the pressure produced by the explosion or rapid combustion (confined in a suitable cylinder) of a mixture containing the proper proportions of air and a gasified fuel. The

source of the fuel gas may be gasoline, kerosene distillate, or even crude petroleum, or it may be generated from coal by distillation in a retort, or by a gas-producer, and the engines are usually designated by the kind of fuel for which they are adapted, as, for example, oil engines, gasoline engines, or producer-gas engines. As far as could be ascertained these latter two are the only types now used in tunneling.

Although the gasoline engine has been developed with wonderful rapidity during the last twenty-five years in connection with the automobile industry, the use of engines of this type for tunnel work has been confined to a very limited field, viz., the operation of isolated or not easily accessible machinery. As prime movers for tunnel plants of any magnitude they cannot compete, under most circumstances, with machines using other forms of power, and, on this account, their application has been confined either to enterprises small in scope or to the temporary and early development stage of larger projects, where they are sometimes installed to begin the work at locations by nature inaccessible for non-portable units of heavier machinery, pending the construction of a special roadway or a transmission line. Most manufacturers of air compressors have recently begun to supply air compressors directly driven by internal combustion engines, although as yet only the smaller sizes of gasoline engines are being used. With suitable adaptations, the principle might be applied equally well to the larger sizes using oil or gas as fuel. Within the last two years gasoline engines have been successfully employed in locomotives for haulage in coal mines, and there are now over one hundred of them in operation. These machines are equally suitable for tunneling operations, and will, no doubt, be used extensively for this purpose in the near future.

The only use of producer-gas engines in tunnel work to date, as far as could be learned, was at the power plant for the tunnel under the Thames River recently completed connecting North and South Woolwich. Since the tunnel was constructed under compressed-air pressure, absolute reliability in the power plant was required to avoid a stoppage of pressure which might

possibly result in serious damage to the tunnel. At this plant, as described in *The Engineer*,* three engines, each of 150 b. h. p. when running at 180 revolutions per minute, were supplied with gas from suction producers using Scotch anthracite coal, and were connected to a central shaft which transmitted power to four air compressors and four dynamos. The plant was operated continuously from July, 1910, until the end of December, 1911, except during October and November, 1910, when after the vertical shaft had been completed the plant was purposely stopped while making preparations to start tunneling.

Although it is not within the province of this report to discuss the gas-producer in any detail, the following brief description is quoted from Bureau of Mines *Bulletin 16:*

"The simplest form of gas-producer for power-gas generation is a vertical cylinder of iron or masonry, lined with fire-brick, having a grate near the bottom, an opening in the top for charging fuel, a smaller opening near the top for the outlet of the gas, and one near the bottom for the admission of air. Openings are also provided at various heights on the sides, through which the interior may be reached for poking the fuel bed, inspecting and cleaning the interior, making repairs, and removing ashes. To prevent the entrance of air except through the proper openings, which are covered by gas-tight doors, the charging opening is generally a small chamber, guarded by gas-tight doors at the bottom and top, which prevents the escape of the gas and the ingress of air while the producer is being recharged.

Simple gas-producers such as described above furnish uncleansed gas, which contains so much dust and other foreign matter that it is unsatisfactory for use, especially in gas engines. Power-gas producers are therefore provided with apparatus for cleansing the gas, known as scrubbers, through which the gas passes after leaving the producer. The scrubber in its simplest form is a cylindrical chamber filled with some porous material like coke or shavings, which is kept constantly wet. The gas, in passing through this wet material, leaves behind most of the solid and liquid impurities it contains.

In addition to the scrubber, many gas-producers have attachments for preheating the air admitted for combustion, so that it enters the fire at a temperature sufficiently high to prevent cooling

* *The Engineer*, London, January 12, 1912, p. 46: "Temporary Power Plant for Woolwich Footway Tunnel," two pages illustrated.

of the fuel. Such attachments make use of the heat of the off-going gases, and are called regenerators.

The form of producer in most general use for generating gas for the development of power, especially in gas engines, is that supplying gas directly to the engine, which draws the air and steam through the fuel bed by means of the suction stroke of the piston. The suction-producer, as it is termed, has been largely restricted to the use of anthracite, coke, charcoal, and other fuels containing a low percentage of tarry compounds. When bituminous fuels are used these tarry compounds are likely to be carried over with the fixed gases into the engine and, condensing there, clog the valves, pipes, and other working parts, despite scrubbing apparatus. Recent improvements in methods of scrubbing, however, have so modified the older practice as to make the use of fuels rich in volatiles comparatively free from such accidents, and their use in the suction type of producer is increasing.

The pressure gas-producer is so designed that the air and steam necessary to develop the gas are forced into the fuel bed under enough pressure to drive the gases generated through the fuel bed and scrubbing apparatus into a gas holder. The gas is thus generated independently of the piston stroke of the engine, and may be thoroughly cleansed of tars and ash before it is used. For this reason the pressure type of gas-producer is well fitted for using bituminous coal, lignite, and peat. The down-draught or inverted-draught gas-producer, in which the heavier products of distillation are all decomposed and changed into simple permanent gases, constitutes a third type. In power-gas producers of this type the heated gases, rich in vaporized hydrocarbons, tars, and heavy gases, are drawn by exhaust fans from the top of the producer, where they accumulate above the freshly added fuel, down through the fuel bed. In the fuel bed, by contact with the heated carbon, they are converted into carbon monoxide and hydrogen, which, after cleansing, can be either stored in receivers or used in engines."

The essential principles in the process of making gas in a producer may be outlined very briefly as follows: In comparison with steam-boiler practice, the fuel bed is very deep and contains three zones—combustion, incandescence, and distillation. A portion of the coal is burned in the combustion zone, where a limited amount of air is supplied for this purpose, and the resulting gases are passed through the remainder of the fuel bed. In the incandescent zone the hot gases combine chemically with some of the constituents of the glowing coal (unburnt

as yet, because of lack of air) and form new gases which have a fuel value. These, together with the gases driven off from the fresh coal by heat in the distillation zone, supply the fuel portion of the mixture exploded in the engine. Steam is also employed in most types of gas-producers because its introduction with the air for combustion assists in the formation of gases of the right composition.

For a more detailed discussion of this subject the reader is referred to the bibliography accompanying this volume.

Although, as far as could be learned, oil engines of the Diesel type have not yet been employed in tunnel power plants, their marked success in other fields more than warrants the discussion of the possibility of their use in tunnel work. The essential feature which differentiates the Diesel machine from other internal-combustion engines is the fact that instead of drawing into the cylinder an explosive mixture containing a combustible gas (such as producer-gas, gasoline vapor, kerosene, or even crude petroleum previously volatilized by heat), and then compressing this mixture and exploding it by means of an electric spark or some other suitable device, the Diesel engine compresses air alone, and when it is under its highest pressure (approximately 300 pounds per square inch, which is much greater than that usually attained in other types of internal combustion engines) injects into the cylinder a spray of finely atomized oil. During the compression of the air to the required pressure it will have reached a temperature of more than 1000° F., more than sufficient to ignite the oil instantly without the use of an electric spark, hot plate, or other similar device.

The chief advantage of the Diesel engine is economy of fuel. It is a well-known fact that the rapidity and completeness of any combustion are greatly increased by pressure; it is not surprising, therefore, that under the higher pressures which prevail in this machine better results can be obtained from a smaller amount of oil. The extremely fine atomization of the fuel due to the jet of compressed air (under a pressure of 300 to 500 pounds per square inch higher than that in the cylinder) by which the oil is injected is undoubtedly another great con-

tributing factor. And again, since the scavenging of the exhaust gases from the previous explosion is effected by air only, instead of a mixture of air and fuel, as is the case in other types of internal-combustion engines, there is no possibility of loss of fuel through the exhaust valves during this process, a saving which is extremely important where the engines are designed for a two-stroke cycle.

In addition to the advantage of fuel economy, however, the Diesel engine does not require frequent cleaning, as is the case with oil engines depending upon a hot plate or a similar device for the ignition of the explosive mixture. It also dispenses with the carbureter, so necessary for the gasoline engine, and which is always a source of more or less trouble and annoyance. And, in addition, since the mixture being compressed in the cylinder of a Diesel engine is not an explosive one, allowance does not have to be made in the design of the cylinder and other parts for undue stresses and strains which might result from a premature ignition of the charge, caused, perhaps, by a glowing piece of carbon on the cylinder wall or by a heated piston, an occurrence which is not infrequent in other engines, as any automobilist will testify. Although some provision can, of course, be made for these shocks, their force and violence cannot always be correctly foreseen or sufficient allowance made for them, and there have been many instances of disastrous results arising from premature ignitions in internal-combustion engines of the usual types.

The principal disadvantage of the Diesel engine, on the other hand, is that of high first cost, and this would prohibit its use for tunnel work of short duration. The price of this machine has recently been greatly reduced abroad, however, and it is certain to be reduced in America, now that manufacturers in this country are equipped with suitable apparatus and prepared to execute the high class of workmanship required in its construction, so that in the near future this drawback may disappear. But even now, if the time required for the completion of the work is to be long enough, or the amount of power to be used is great enough to warrant a heavy initial outlay in order

to effect a saving in operating cost, the choice of a Diesel engine should be seriously considered.

ELECTRIC MOTORS.—Electric motors may be designed either for direct or alternating current. Where used as prime movers at the tunnel plants visited they were of the second type only and operated at comparatively low voltages, 440 volts being the usual figure. Their power was generally transmitted to the remainder of the machinery by means of belts, but at one or two places on the New York Aqueduct, "direct-connected" electric-driven air compressors were noticed.

TRANSMISSION OF POWER

Electricity, because of its economy and its freedom from limiting distances, is the favored means for transmitting to a tunnel the power generated at some remote station. It possesses one well-known disadvantage, that of occasional interruption, especially where distances are great and tension high, because of unavoidable hindrance to service due to electrical storms or other atmospheric agencies. On the other hand, producer-gas transmission has possibilities which deserve to be considered seriously in this connection. This form of conveying power has been recently taken up from the realm of mere conjecture and demonstrated as a practical system, both in this country, at Pittsburgh where natural gas is piped over distances as great as 200 miles, and in England, where producer gas is supplied to points within a radius of 160 miles, with transmission losses even less than when electricity is used. In its application to tunnel operations, producer gas can be generated in a plant conveniently situated on a railroad siding or some other readily accessible place, and the power piped to internal-combustion engines at the tunnel portal.

Where distances are comparatively short (that is, less than five miles or so) electricity is rivaled by compressed air, and the competition grows more keen as the length of the transmission system decreases. This is possible because where pneumatic drills are employed, compressed air, in spite of its

low efficiency and high cost, is necessary for their operation; and even were electric transmission chosen, the power would need to be converted ultimately into compressed air at the tunnel. Hence it is the usual practice to produce the compressed air at once, thus avoiding the extra machinery and the additional operating losses of electric transmission.

CHOICE OF POWER

A number of factors enter into the choice of power for tunneling operations. To begin with, the plant is usually short lived. Then, too, the influence of such local conditions as accessibility, distance from a railroad, the availability of water-power, etc., is strongly felt. Each method of deriving power has also certain peculiarities which render it particularly adaptable to different conditions. Among these may be mentioned the cost of installation, of labor, of fuel, of interest and depreciation, and other operating expenses. Aside from all this, it is often necessary to decide between the production of power at the plant or elsewhere and the purchase of power from an established hydro-electric company. Some of these factors we shall discuss briefly.

Duration of Plant.—At many tunnel power plants, in direct contrast with those used in manufacturing, the equipment is required only for the comparatively short time of actual tunnel construction. Thus it becomes a delicate problem to determine just how far one is justified in the purchase of machinery and apparatus for utilizing all the various economies that may be effected in the production of power. It is difficult to decide whether it would not be better in the end to install less costly machinery that would necessitate slightly higher expense in operating and maintaining than to tie up extra capital in equipment that would be of no further use when the tunnel is completed. Of course, the shorter the probable life of the plant the more would one be justified in such a course; although, if the equipment can be transferred upon the completion of the tunnel to other projects, this would so prolong its period of

usefulness that the original expenditure of capital could properly and with true economy be greater. A notable instance of this was observed on the Los Angeles Aqueduct, where as far as possible, upon the completion of one of the numerous tunnels, the equipment was transferred and used in power plants at other tunnels whose construction had not yet been begun. If a central station is being considered, where a large amount of power is to be generated, the purchase of apparatus from the main viewpoint of economy in operation is again the far-sighted policy. This was the case at the Rondout Siphon Tunnel, but at the average mining tunnel or adit the converse is more often likely to be true.

ACCESSIBILITY.—Tunnels are often located at places very difficult of access. They may be so situated as to make the installation of heavy machinery no easy matter, as, for example, where the road from the nearest railroad is poor and the grade very steep; or they may be at a great distance from the nearest siding, so that if a form of power be chosen that requires coal, the delivery of this fuel is not only very costly, but also most uncertain and difficult in some seasons of the year. Such conditions are favorable for the adoption of power transmission in some form from a waterfall or rapid, if one be located near enough, or, lacking these natural advantages, from a fuel plant installed at some point more readily accessible.

COST OF INSTALLATION.—The cost of installing water-wheels is entirely dependent upon local conditions, which are never twice alike. Where high heads are available and the quantity of water required is not large, it can be conveyed to the water-wheel by small flumes or pipes which are comparatively inexpensive. For example, at the Carter tunnel (see Figure 10), with an available head of 145 feet, a flume 16 by 48 inches inside and 5,000 feet in length is sufficient to supply the 200 horsepower developed. At the Laramie-Poudre tunnel, with a static head of 268 feet, 400 horse-power was conveyed to the tunnel plant by a wooden-stave 22-inch pipe line, 8,500 feet in length. The Utah Metals tunnel secures water from two sources: the first has a 700-foot head, using 2,500 feet of 12-inch,

1,900 feet of 10-inch, and 100 feet of 8-inch spiral steel riveted pipe, furnishing 170 horse-power; the second, with 750 foot head, employs 2,000 feet of 12-inch, 1,000 feet of 8-inch, 3,000 feet of 6-inch pipe in producing 55 horse-power. Where heads are low, however, retaining dams are usually necessary. At

FIG. 10. View showing end of flume, mill, dump, and other surface features at Carter tunnel.

best these are a costly expedient and their expense increases enormously with their height. With low heads, larger flumes are also required to convey the greater quantity of water. At the Nisqually tunnel, illustrated in Figure 11, a low dam and a wooden flume 6 by 8 feet in cross-section and 1,200 feet long were used. The water was delivered to a turbine wheel under an effective head of 29 feet which generates 1,000 horse-power. One has only to consider some of the very expensive dams on the

FIG. 11. View showing power-house, portal, and part of flume, Nisqually tunnel, Alder, Washington.

larger rivers, furnishing power for manufacturing purposes, in order to realize how great the cost of installation may be where low heads only are utilized. It is fortunately true, however, that where water-power is obtainable for tunnel work high heads are usually available also, and the less expensive flumes or pipe lines of moderate length can be utilized.

The cost of the machinery actually within a tunnel power-house is greater for steam than for water-power or electricity; but if, as should be done to make the figures truly comparable, the cost of the dam and flume (or of the transmission line for electricity) be taken into consideration, the advantage is usually reversed. It is somewhat cheaper to install a steam plant than one using producer gas and having engines of the same capacity, but the difference is not great. R. H. Fernald,* after a study of many tables of costs, applying to other uses, however, than tunnel work, concludes that "complete producer-gas installations for the larger plants, say from 4,000 to 5,000 horse-power, cost about the same as those of first-class steam plants of the same rating. With smaller installations the balance is probably in favor of the steam plant." Since it is not customary in tunnel work to install machinery designed to effect all the refinements of steam economy found in permanent plants, it is probable that the first cost of the average steam plant for tunnel work is less than those upon which Mr. Fernald's estimates are based, in which case the comparison would be even more favorable to steam. This is partly offset by the fact that the price of gas-producers and engines is constantly being lowered, and by the fact that the cost of actually placing the machinery would be less for the gas-producer—considerably in some cases, appreciably in all.

The initial expense of installing any of the various systems for transmitting power is dependent upon two factors: (1) the cost of the machinery required to produce the power, to convert it into the form suitable for transmission, and to reconvert it into the form adapted to the machines using it; and (2) the

* Bull. 9, B. of M., p. 31.

cost of the transmission line. Except for a slight increase in capacity, to provide for losses in transmission, the factor of machinery cost under any given conditions is independent of the distance over which power is to be delivered, but the cost of the line, as will become apparent later, increases considerably faster than its length, other things being equal. If the power is required ultimately for the operation of air drills, practically the same size of compressor will be necessary whether electric, air, or gas transmission is employed, and the cost of boiler, engine, foundations, etc., in the case of electricity or air will approximately balance the cost of the producer, engine, foundations, etc., for gas. Air transmission would require practically no other machinery than that just mentioned; but gas, on the other hand, would need a blower of some sort to force it through the line, while electricity would require, in addition, a generator, motor, transformers, extra foundations, etc. A list of the three forms of power transmission made, according to increasing machinery-cost factor, would be air, gas, and electricity.

The cost of an electric-transmission line may be divided into three parts: first, the metallic part of the circuit; second, insulating the conductor; and, third, erecting or installing the line. Although a detailed discussion of this subject is beyond the proper scope of this book, it can be shown that, for a stated power loss and a given distance, the weight of the metallic conductor required to transmit a definite amount of power is inversely proportional to the square of the voltage employed. On the other hand, the cost of insulation increases rapidly with the potential, and the cost of erection, complicated by steel towers, etc., is greatly augmented at high voltages. Thus the economical transmission of a given amount of power for a stated distance is limited by the maximum voltage which may be used without the increased cost of installation and erection destroying the saving in the cost of copper.

Any attempt to go into the complicated processes necessary to ascertain the most advantageous voltage for a long distance-transmission line would be out of place here; but, for the short

distances and small amounts of power commonly employed in tunneling operations, the following rule of thumb will suffice to give a close approximation to the most carefully made calculations. Multiply the distance to be traversed in miles by 1,000 and select the voltage of the nearest commercial size of transformer to this figure. The standard voltages of transformers now in use are 220, 440, 660, 1,100, 2,200, 6,600, 11,000, 22,000, 33,000, 66,000. For instance, if the distance from the power station to the tunnel plant is five miles, select a voltage of 6,600; if the distance is ten miles, a voltage of 11,000. Where the distance falls midway between transformer steps, use the voltage which will find most ready sale for the apparatus when the work is completed.

Since there are certain difficulties in the construction of direct-current generators for voltages higher than 600, alternating current is generally employed for transmission lines. This form also possesses a very important additional advantage in the ease with which it may be changed from low to high potential, and vice versa. When high tension is employed in transmission of electrical power, the voltage at the generating station is usually comparatively low, and is "stepped up" by transformers to the desired potential for the line and is reduced again by transformers at the tunnel plant.

The following figures, which show the installation cost of an electric-transmission line for different voltages and distances, assuming approximately 10 per cent drop in the line, are based upon data kindly furnished by the General Electric Co.*

1. 200 H.P.—1 mile—440 v., direct current.

Poles, cross-arms, insulators, and fittings (poles spaced 100 feet)	$375
33,000 lbs. copper cable, 500,000 C. M. (four conductors required), at 18¼ cents lb.	6,025
Cost of erection	300
Total	$6,700

* Freight, right of way, surveying, and engineering are not included in these data.

2. 200 H.P.—1 mile—440 v., 3-phase, 60-cycle, alternating current.

Poles, cross-arms, insulators, and fittings (poles spaced 100 feet)	$415
34,000 lbs. copper cable, 350,000 C.M. (six conductors required) at 17¾ cents	6,035
Cost of erection	375
Total	$6,825

3. 200 H.P.—1 mile—1,100 v., 3-phase, 60-cycle, alternating current.

Poles, cross-arms, insulators, and fittings (poles spaced 125 feet)	$385
5,100 lbs. copper cable, B. & S. No. 0 (three conductors required) at 17¾ cents	905
Cost of erection	265
Six transformers, 1,100: 440 volts, with switches, etc., erected	2,900
Total	$4,455

4. 200 H.P.—5 miles—1,100 v., 3-phase, 60-cycle, alternating current.

Poles, cross-arms, insulators, and fittings (poles spaced 125 feet)	$1,870
122,000 lbs. copper wire, B. & S. No. 000 (nine conductors required) at 17¾ cents	21,650
Cost of erection	1,580
Six transformers, 1,100: 440 v., with switches, etc., erected	2,900
Total	$28,000

5. 200 H.P.—5 miles—6,600 v., 3-phase, 60-cycle, alternating current.

Poles, cross-arms, insulators, and fittings (poles spaced 125 feet)	$1,870
6,500 lbs. copper wire, B. & S. No. 6 (three conductors required) at 17¾ cents	1,150
Cost of erection	1,080
Six transformers, 6,600: 440 v., with switches, etc., erected	3,700
Total	$7,800

6. 200 H.P.—25 miles—6,600 v., 3-phase, 60 cycle, alternating current.

Poles, cross arms, insulators, and fittings (poles spaced 125 feet)	$9,350
103,000 lbs. copper wire, B. & S. No. 1 (three conductors required) at 17¾ cents	18,300
Cost of erection	5,150
Six transformers, 6,600: 440 v., with switches, etc., erected	3,700
Total	$36,500

7. 200 H.P.—25 miles—22,000 v., 3-phase, 60 cycle, alternating current.

Poles, cross arms, insulators, and fittings (poles spaced 125 feet)	$9,900
33,000 lbs. copper wire, B. & S. No. 6 (three conductors required) at 17¾ cents	5,860
Cost of erection	5,190
Six transformers, 22,000: 440 v., with switches, etc., erected	5,200
Total	$26,150

The Pneumo-Electric Machine Co.* have estimated that if compressed air were used to transmit 200 horse-power one mile, allowing 10 per cent. loss at 80 pounds pressure, an 8-inch pipe would be required which, at $1.78 per foot, would cost $8,400. Calculations show that in order to transmit the same amount of power in the form of producer-gas containing 120 B. t. u. per cubic foot, the required pipe would need to be only 4 inches in diameter, costing, at 70 cents per foot, approximately $3,700. To both these values should be added the expense of laying the line, but this figure would be relatively small compared to the cost of the pipe.

Where the power is ultimately required for use in air drills and is to be transmitted only for short distances, compressed air is the cheapest of the three methods as regards installation cost, the higher machinery factor required by the other systems more than balancing the expensive air pipe-line. The field for producer-gas transmission (with its machinery factor slightly

* *Mining and Scientific Press*, May 14, 1910, p. 700.

greater than air yet less than electricity, and its line factor just the reverse) lies in the medium distances—beyond the economical range for air, but still too short to warrant the cost of the extra electrical machinery. For long distances, on the other hand, electric transmission at high tension is, of course, preeminent.

LABOR.—Tunnel power plants are generally not large enough to occupy the entire time of even one operator, hence it is impossible to prevent their being over-manned. The amount of labor required does not as a rule, therefore, seriously affect the choice of power. At a tunnel plant using water-wheels, hydraulic air compressors, or electric motors as prime movers, one man per shift is sufficient. Even then, as was the case at the Laramie-Poudre tunnel, it is not unusual to make these 12-hour shifts, thus requiring but two men per day; or, as at the Carter tunnel, for a portion of his time the engineer is employed at other work. If the results obtained from practice in other lines be accepted, a producer-gas plant would require no more exacting attention, it being not unusual for one man per shift to operate plants which develop as high as 750 or 1,000 horse-power. A similar steam plant, on the other hand, would require at least two firemen in addition to the engineer. In larger steam installations the amount of labor required is naturally not so great in proportion to the horse-power produced. For example, at the Rondout Siphon 8 men per 8-hour shift were able to operate a steam plant rated at 4,000 horse-power and containing 10 air compressors of 2,400 cubic feet capacity each.

FUEL CONSUMPTION.—If the charge for delivering it be included in the price, at most tunnel plants the cost of fuel is high, hence the amount of it required is of great importance. Steam plants require much more coal than gas plants of the same size; for although in large installations, with every means for effecting thermal economies, steam plants may be operated with as little as two pounds of high-grade fuel per brake horse-power hour, in small plants such as are used in tunnel work a fuel consumption as low as three pounds would be exceptional, and four or five pounds is more likely to be required. With producer-gas, on the other hand, it has been repeatedly demonstrated that internal

combustion engines can be operated on less than one pound of coal per brake horse-power hour, and at the best plants this figure runs as low as three-fourths of a pound. The consumption at the Woolwich tunnel plant during a test was .727 pound of Polmaise Scotch anthracite per brake horse-power hour. The small internal combustion engine has also the additional noteworthy characteristic of being decidedly efficient in small sizes. The gas engine of 50–60 brake horse-power has but a very little greater fuel consumption per horse-power than the large engines of 500 or 1,000 brake horse-power. The adoption of a producer-gas plant also makes possible the utilization of the fine sizes of anthracite coal such as Nos. 1, 2, and 3 buckwheat, which were formerly considered waste, but which are now being screened and saved and may be procured at much less cost than the coal used in most steam boilers.

Thermal Efficiency.—The comparatively high fuel consumption of the steam-engine is due to its low thermal efficiency. Although large and economically operated steam plants may realize perhaps as high as 12 to 15 per cent. of the theoretical energy contained in the coal, 5 per cent. is much nearer the value generally obtained in ordinary tunnel work. The following table shows the distribution of the average heat losses for one year at a well-conducted steam plant where the thermal efficiency at the fly-wheel was 10 per cent.:

LOSS OF THEORETICAL HEAT ENERGY AT A STEAM PLANT

Losses due to imperfect combustion, heat absorbed in ashes, moisture, etc., heat in flue gases, radiation, etc.	25%
Loss due to latent heat in exhaust steam	60
Loss in steam pipes and auxiliaries	3
Loss due to friction in steam-engines	2
	90%

The producer-gas engine, on the other hand, operates with a much higher thermal efficiency, 20 to 30 per cent. being not unusual in actual practice. Recent exhaustive shop tests of a number of first-class foreign-built producer-gas engines, ranging

in power from 70 to 120 horse-power, gave thermal efficiencies at full load of from 31.3 per cent. to 34.9 per cent., and a coal consumption of from .72 to .623 pounds per brake horse-power hour. The following table, introduced for comparison, shows the distribution of losses in a producer-gas plant operating with similar economy to the steam plant above:

THERMAL LOSSES IN PRODUCER-GAS PLANT

Loss in gas-producer	15%
Loss in water jacket	21
Loss from radiation and friction	4
Loss in exhaust gases	35
	75%

Purchase of Current.—If the line of an established electric power company runs near enough to the tunnel plant, power is often purchased in preference to generating it at the tunnel. In such cases the price of current usually ranges from 1½ to 2 cents per kilowatt hour. On the Los Angeles aqueduct the power used at all the tunnel plants is obtained from a private transmission line operated by a separate department of the aqueduct organization, and a flat rate of 1.7 cents per kilowatt hour for power is charged against each tunnel, which it is estimated is sufficient to operate the system and eventually pay for its installation. At one of the tunnels in Colorado, a flat rate of $2.50 per horse-power month is charged, to which is added 1.3 cents per kilowatt hour used. On a 24-hour day basis this is equivalent to 1¾ cents per kilowatt hour. At another tunnel in Colorado, 2 cents per kilowatt hour is the price of current. At a third, the power for the compressor costs $5.50 per horse-power month, which is equivalent to 1 cent per kilowatt hour on a 24-hour day basis, but at the same tunnel 2 cents per kilowatt hour is charged for the current used in the motor generator set which operates the trolley system, making the average cost for the total power used approximately 1½ cents. At one tunnel plant using a very large amount of power, the current is said to have cost but ⅞ cents per kilowatt hour, an exceptionally

low figure, but in this case other considerations were involved which really made the cost of the electricity greater than this.

The following schedule is used by a number of western hydro-electric companies who claim that this method of making a charge is "fair and rational."

Fixed Charge per Month per Horse-Power of Maximum Demand		Energy Charge
For the first 100 Horse-Power..	$3.25	Add for all energy used as shown by meter thirteen mills per kilowatt hour for the first 40,000 kilowatt hours used each month, and five mills per kilowatt hour for all additional energy.
For the next 400 Horse-Power..	2.25	
For the next 500 Horse-Power..	1.75	
For all additional Horse-Power.	1.00	

The maximum demand shall be determined by the company's meters, disregarding starting peaks and those due to short circuits or accidents to user's apparatus.

INTEREST AND DEPRECIATION.—The cost for interest per unit of power is dependent upon the amount of capital invested, but that for depreciation is somewhat more complicated. In the case of water-power, a dam or a ditch would have but very little salvage value after the completion of the tunnel; something further might be realized from a pipe-line or flume and still more from the machinery in the power-house, the total loss of capital invested being the sum of these separate items. Hence the charge for depreciation would depend upon the relation of the different factors to the total cost of installation. A similar analysis may be made for other means of producing power. Both interest and depreciation charges are dependent also upon the hourly use of the plant per day, it being evident that if the plant were used 24 hours instead of 12 the same total cost for interest and practically the same total loss by depreciation would be distributed over double the number of horse-power hours, and hence be proportionally less.

CONCLUSIONS

In choosing the power to be used for tunnel plants, a waterfall or rapid, if either is available, should be given primary consideration. The chief arguments in favor of this source of power are as follows: no fuel is required; the cost for attendance and repairs is a minimum; it is comparatively reliable, hence obviating losses due to interruptions of service. The one factor which might prohibit its choice is the possibility of a high cost of installation, with resulting large charge for interest and depreciation per unit of power. This consideration, dependent entirely upon local conditions, usually determines the adoption or rejection of a possible water-power plant. Again, where water-power is not obtainable directly at the tunnel plant, if it can be secured from a waterfall in the neighborhood, the essential factors remain the same with the exception that a means of transmitting the power, such as air or electricity, must be chosen, and the cost of the transmission system be included in the cost of installation. Another possible means of obtaining the advantages of water-power is to be found in the purchase of current from an established hydro-electric company. Such a concern is in a position to utilize a waterfall, too distant to warrant its development for a single tunnel project, and by distributing a large amount of power among many permanent customers is enabled to sell it very cheaply. In such case, to the price of the power should be added the cost of attendance at the tunnel plant and the interest and depreciation charges on the necessary equipment. Allowance must be made for interruptions to service in long-distance electrical transmission which are neither unusual nor avoidable.

The choice of machinery for utilizing water-power is also largely governed by local conditions. Since high heads, for which impulse-wheels are especially adapted, are generally to be found where water-power is available for tunnel work, this type of machine is properly chosen in most instances. Turbine wheels may be used where the water is clear or can be settled in a reservoir, but such conditions are not usually to be found at tunnel power plants. The hydraulic compressor, although prac-

tically automatic and entailing but a small operating expense, is so costly to install that it is scarcely to be considered except for plants much larger than those usually designed for tunnels.

According to usual practice, a steam plant would be installed if water-power were not available and electricity were not purchasable. This is difficult to understand unless it be attributed to the supposed unreliability of the gas-producer. The usual steam plant for tunnel purposes is, as has been shown, very inefficient in its utilization of the energy of coal and has a fuel consumption rarely less than 4 or 5 pounds per horse-power hour. As regards cost of installation, the balance is slightly in favor of steam, but not sufficiently so to overcome the disadvantage of higher operating cost.

The producer-gas plant, on the other hand, is several times more efficient in its utilization of heat energy, making possible the production of a brake horse-power per hour in some instances with as little as one pound of coal. With this plant it is also possible to utilize cheaper grades of fuel. The manufacturers of air compressors have recently adapted their machines for use with internal-combustion engines. It would seem, therefore, if a plant using fuel were necessary, that the installation of a producer-gas plant under most conditions were more desirable than a steam plant.

As a means of transmitting power for any great distance the balance is preponderantly in favor of electric transmission at high tension. In tunnel work and over comparatively short distances, compressed air is able to compete with it because the air drills require this form of power for their operation. When it is necessary to obtain power from coal there seems to be a field for producer-gas transmission in the medium distances, where the cost of the line and the power losses in transmission prohibit the use of air, but where the cost of the extra electrical machinery is still not warranted by the saving in cost of line.

CHAPTER V

AIR COMPRESSORS

ALTHOUGH an air compressor is the machine invariably chosen at tunnel plants to convert the power derived from steam, water, electricity, or fuel gas into a form suitable for use in pneumatic rock drills, many factors enter into the problem of its selection. After the question of motive power and capacity, the type of the compressor is, perhaps, the next thing to be considered. The methods of regulation under varying load likewise deserve attention. And, finally, the devices and accessories for preventing or neutralizing the effects of heat produced during compression and for removing moisture from the air bear directly upon our problem.

The most familiar types of air compressors consist essentially of a cylinder in which air is subjected to pressure by a moving piston. Automatic means are provided to insure the admittance of free air and its delivery after compression, and the momentum of a fly-wheel is required to equalize the irregular demands of the piston for power. When steam or internal combustion engines are the prime movers they are usually, though not necessarily, incorporated with the compressor, the power and air pistons being connected by a common piston rod or engine shaft. Where water or electricity is employed, the power is usually developed in separate motors and transmitted to the air compressor by a belt, the fly-wheel of the compressor in this case serving also as a pulley; but there has arisen lately a growing demand for the "direct-connected" electrically driven machine in which the electric motor forms an integral part of the compressor, the armature serving as a fly-wheel. Such machines are now supplied by all the leading manufacturers. "Direct-connected" water-power driven air compressors are also obtainable in which the water-wheel carrying the buckets or vanes performs the additional function of fly-wheel for the com-

pressor. Air compressors of an entirely different type, operating on the principle of the reverse turbine, have recently been placed on the market. They are especially adapted to take advantage of the high rotative speed of electric motors and steam turbines. Although the Taylor hydraulic system is, strictly speaking, an air compressor, it has been described somewhat in detail as a means of utilizing water-power; since its use is ordinarily confined to units too large for tunnel work, it will not be discussed further.

POWER REQUIRED

Although the kind of motive power is generally predetermined, in designing a given plant, by local conditions, the amount of power required for this purpose is worthy of brief discussion. E. A. Rix is authority for the statement* that, in compressing air from atmospheric pressure to 90 or 95 pounds,† 20 brake horse-power must be delivered at the fly-wheel shaft of a reciprocating compressor for every 100 cubic feet per minute of piston displacement. This figure is deduced as the average result of a number of tests of air-compressor plants, comparing the capabilities of almost every kind of compressor with the actual power required to operate them. He also states that the figures given in trade catalogues for the amount of power required in compressing air are usually somewhat lower than this value, but it must be explained that such figures are theoretical and do not take into consideration the mechanical or volumetric efficiencies of the compressor. The following tables are computed from the catalogues of two leading manufacturers for a popular type of compressor in each case and show the rated brake horse-power per 100 cubic feet cylinder displacement, where the final gauge pressure is 100 pounds.

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* Address before the Mining Assoc., Univ. of Calif., February 19th, reprinted *Compressed Air Magazine*, June, 1906, p. 4894.

† Throughout this book when air pressure is mentioned the figures given will be those above atmosphere, *i.e.*, gauge pressure. In many books the pressures given are absolute, *i.e.*, the pressure above vacuum, while in European works on the subject pressures are generally expressed in terms of atmospheres, which in this country would be liable to create considerable confusion.

RELATION BETWEEN REQUIRED BRAKE HORSE-POWER AND CAPACITY

Compressor A		Compressor B	
Capacity Cu. Ft. per Minute	Brake Horse-Power Required for Each 100 Cu. Ft. Displacement Compressing to 100 lbs.	Capacity Cu. Ft. per Minute	Brake Horse-Power Required for Each 100 Cu. Ft. Displacement Compressing to 100 lbs.
144	18.7	248	19.3
247	18.6	338	19.2
372	18.4	537	18.1
534	18.3	680	18.1
704	18.1	873	18.0
1051	18.0	1056	18.0
1312	17.8	1188	18.0
1692	17.7	1414	17.9
2381	17.7	1845	17.9

It will be observed that these tables bear out the statement made by Mr. Rix, and that even in spite of the increased final pressure, the values are somewhat less than the one he proposes. They also show that in machines of large capacity proportionally less power is required.

The following table, based upon published figures, shows the amount of power required or provided per 100 cubic feet of free air actually compressed at several turbo-compressor installations:

POWER CONSUMPTION OF TURBO-COMPRESSORS

Pressure	Capacity in Cu. Ft. Free Air per Minute	Rated H.P. of Motor or Engine per 100 Cu. Ft. of Free Air When Compressing to Stated Pressure	Actual H.P. Required in Compressing 100 Cu. Ft. of Free Air per Minute to Stated Pressure
90	4,600	21.8	....
118	21,250	18.8	17.
135	20,000	....	18.5
170	22,000	18.2	....

CAPACITY

The capacity of compressors is rated in free air,* and in reciprocating machines is equally based upon speed and piston displacement—that is to say, the number of cubic feet of cylinder space swept by the piston each minute at the given speed.

*Free air is air at 14.7 lbs. pressure (atmospheric), and at a temperature of 60° F.

This is not, however, the actual capacity, because there are unavoidable losses in volume due to clearance, piston speed, leakage, and expansion, the sum of which may amount to as much as 30 per cent. of the rated capacity in a single-stage compressor at 100 pounds pressure. The capacity of turbo-compressors is based on the amount of free air drawn into the intake per minute. Although some of the more carefully designed reciprocating compressors may give a volumetric efficiency as high as 90 per cent., for compressors such as are customarily employed in power plants for tunnels 80 per cent. is more likely to be nearer the figure. While the tables shown in manufacturers' catalogues of air drills are in the main fairly accurate for new drills, the air consumption is often greatly augmented as the parts become worn. Provision must be made also for leakage in the pipe line and for the air required by drill sharpeners, blacksmith forges, and an extra small drill which is sometimes used for blocking and trimming. It is therefore most desirable to have the air compressors, as based upon catalogue rating, considerably oversized, and in tunnel practice this usually ranges from 100 to 150 per cent. The following table shows a comparison between the rated compressor capacity and the catalogue air consumption for the drills employed in the heading at several tunnels:

RELATION BETWEEN COMPRESSOR CAPACITY AND AIR CONSUMPTION OF DRILLS

Tunnel	Compressor Catalogue Values		Drills		Oversize of Compressor*
	Speed r.p.m.	Capacity Cu. Ft. per Min.	No. in Heading	Air Consumption from Catalogue Cu. Ft. per Minute	
Carter	150	868	2	230 at 9,000 elev.	280%
Laramie-Poudre	165	602	3	250 " 8,000 "	140
Elizabeth Lake	160	736	3	185 " 3,000 "	300
Lucania	130	544	3	250 " 8,000 "	120
Marshall-Russell	175	487	2	200 " 8,000 "	140
Mission	190	247	1	100 " 1,200 "	150
Rawley	175	427	2	190 " 10,000 "	120
Snake Creek	165	680	2	300 " 6,000 "	125
Strawberry	175	427	2	300 " 7,000 "	40

* Not including drill sharpeners, forges, or leakage in pipe lines.

The decrease in effective capacity of the compressor caused by leakage in pipe lines is in many cases not fully realized, and steps are not taken either to determine the amount of this waste or to prevent it. Where the compressed-air lines are constructed with great care and covered so as to protect them from accident or from extremes of temperature, the loss by leakage may be slight or almost negligible; but where they are not well built or where they remain uncovered, the lines on the surface are exposed to injury from numerous causes—not the least of which being diurnal and seasonal variation in temperature—and those underground are apt to be struck by falling rock, derailed cars, etc. In such cases the leakage is likely to be a very considerable item, and the greatest care should be taken to test the lines at short intervals to ascertain the amount of loss in order that whatever is necessary may be done to stop it. Where reciprocating compressors are used, driven either by steam- or water-power, it is an easy matter to ascertain the amount of leakage by simply closing all of the outlet pipes from the line and noting the number of strokes per minute necessary to maintain the desired pressure; but where turbo-compressors are used, unless a very careful table has been compiled showing the output at different speeds and pressures, the leakage can best be ascertained by stopping the compressor when the receiver and lines are filled, allowing the pressure to drop to 50 per cent., let us say, then starting up the machine and noting the length of time required to bring up the pressure to the original point. While this does not give exact results, still it will furnish a useful, if not exactly correct, index to the rate at which the compressed air is escaping. Such a method of ascertaining the amount of leakage is so simple that it would seem that it ought to be in general use; but unfortunately it appears to be the habit of workmen, especially of the "chain gang," to assume that all air lines are much more free from leaks than they really are. A few years ago at one of the large mines in the West which operated a great number of drills, drill sharpeners, and pumps by compressed air, it was found impossible to maintain the required pressure, and bids for a new and expensive compressor were

called for, when it occurred to the management to test the pipe lines by the method above indicated, and it was discovered that 1,100 horse-power were required to supply the loss by leakage. In this case the "chain gang," instead of the machine shop, "got busy," and in a week the leakage was stopped and the waste of air reduced to such a point that, instead of buying another compressor, one of the largest machines was shut down.

TYPES

Reciprocating air compressors may be divided into two general types: "straight-line" (sometimes called "tandem") and duplex. Either of them may be single stage where the air reaches its final pressure in one cylinder, or multi-stage where only a portion of the compression takes place in the first cylinder and is finally completed in a second, third, or even fourth cylinder.

STRAIGHT-LINE

In the tandem compressor, if it be driven by steam or an internal combustion engine, the power and air cylinders are placed tandem-fashion along a common piston rod, and the

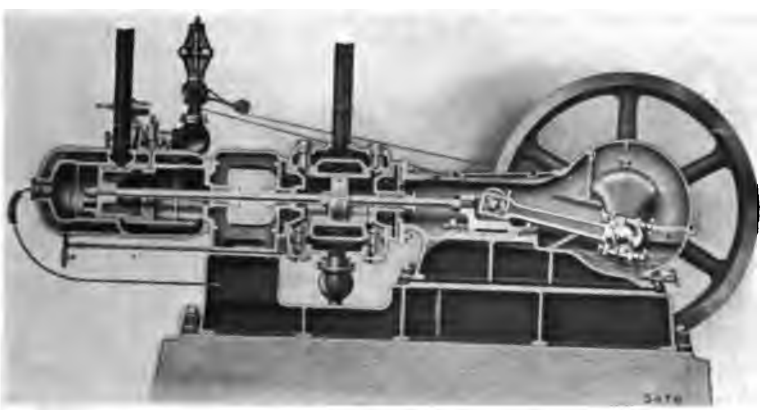

FIG. 12. Section through a single-stage straight-line compressor in which the power cylinder is an internal combustion engine using gasoline fuel.

power is thus applied in a straight line. (See Figures 12 to 14.) The fly-wheels, of which there are usually two, may be at either

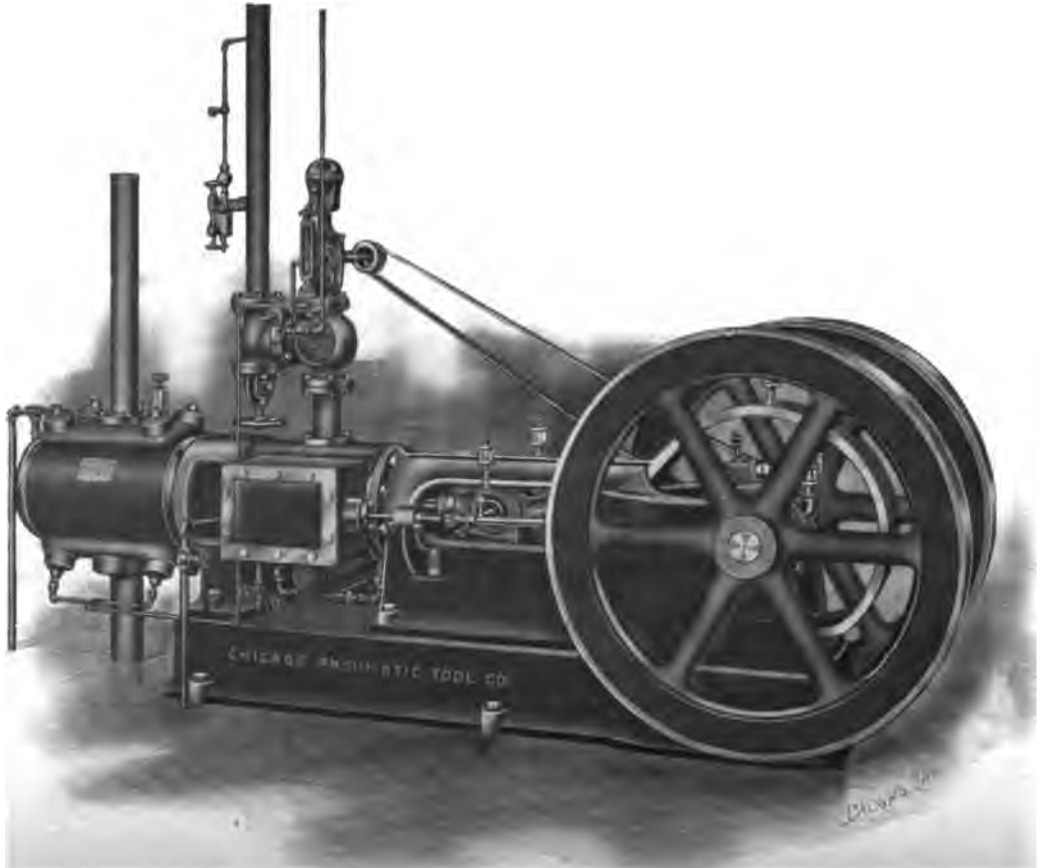

FIG. 13. Single-stage, tandem, steam-driven compressor.

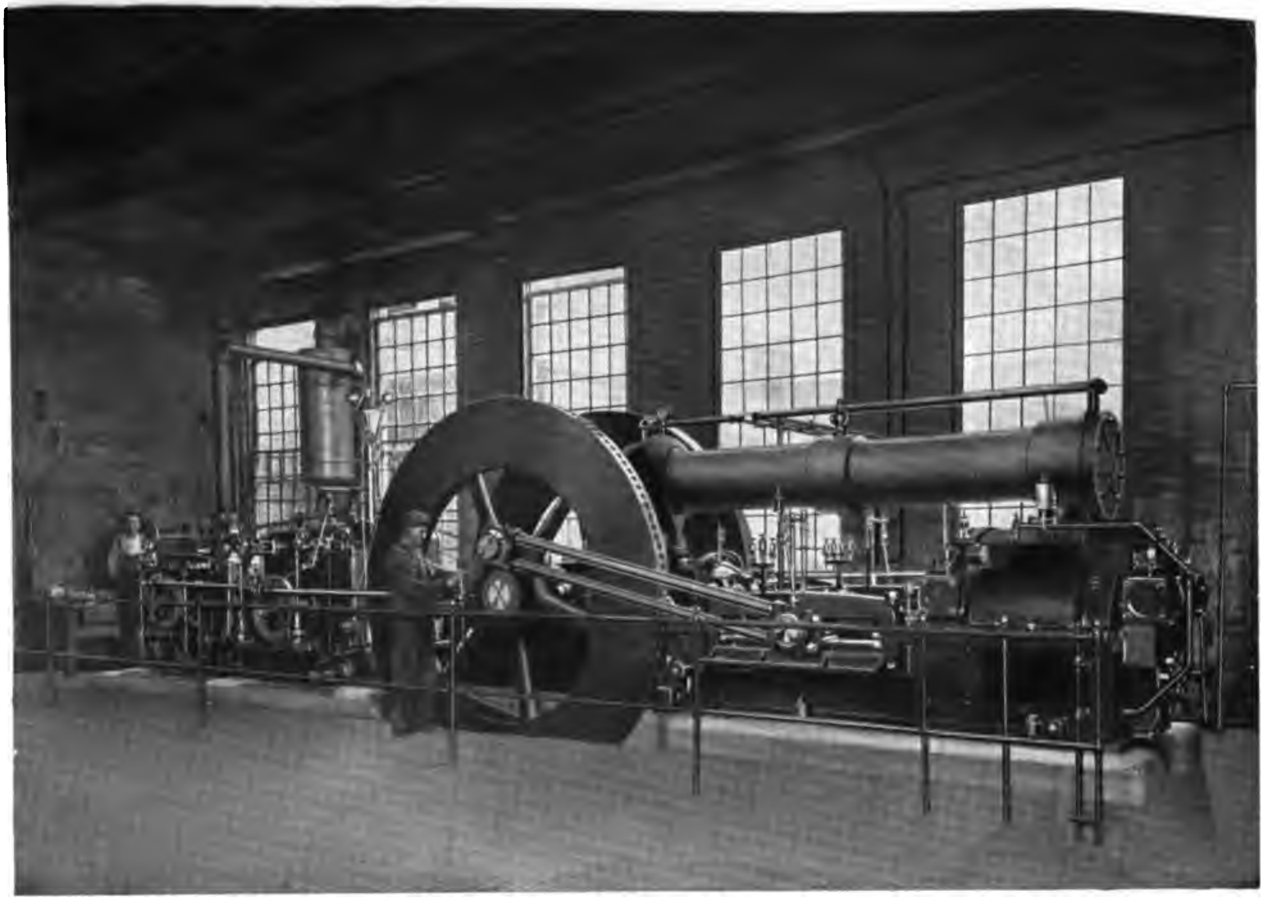

FIG. 14. Tandem, two-stage, steam-driven compressor with Corliss compound-steam cylinders.

end or between the cylinders and are connected to the piston rod by a cross head and ordinary connecting rods. If it be driven

FIG. 15. Single-stage, power-driven compressor.

by electricity or water, practically the only change is the omission of the power cylinder. (See Figures 15 and 16.)

DUPLEX

A duplex compressor consists of two tandem compressors placed side by side, having a fly-wheel between them on a com-

FIG. 16. Belt-driven, straight-line, two-stage compressor.

mon shaft. The two sides are connected to the fly-wheel shaft by cranks set at 90° so that when one side is encountering maximum resistance, the other is working under the lightest load. There are many different combinations possible with the duplex type. The steam cylinders * may or may not be compounded (see

* Internal combustion engines have not as yet been applied to this type of compressor.

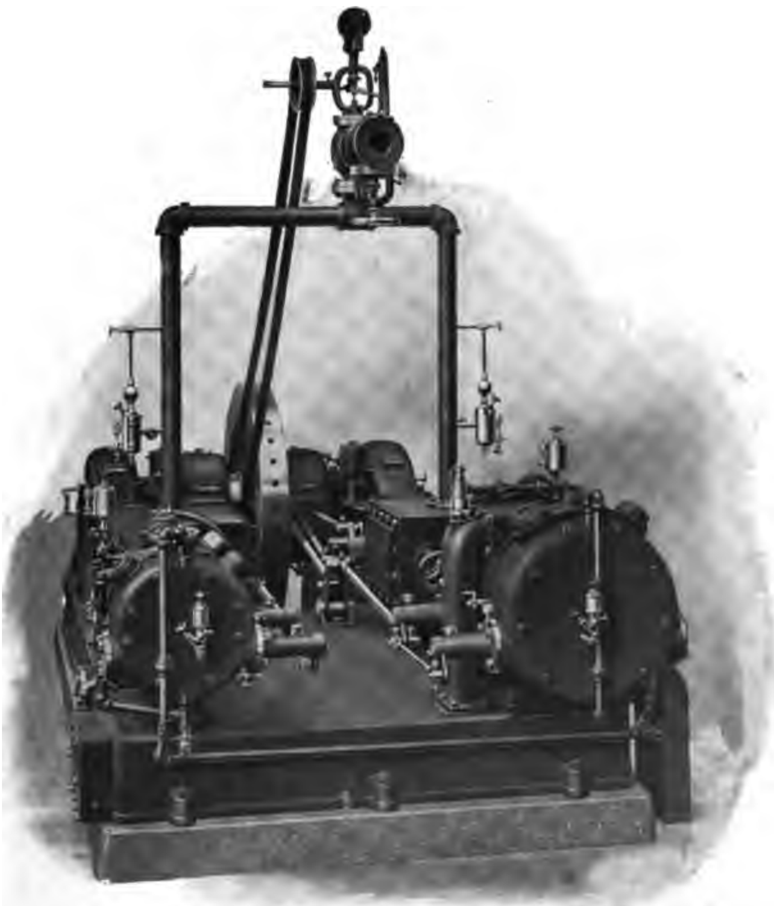

FIG. 17. Duplex, simple-steam, two-stage air compressor.

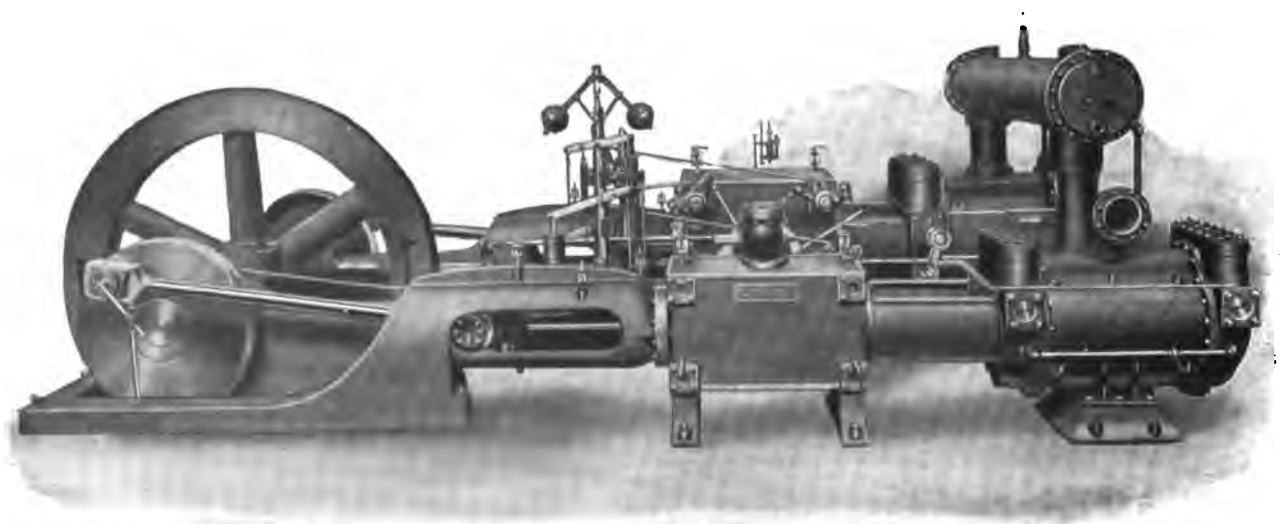

FIG. 18. Duplex, compound steam, two-stage air compressor.

Figures 17 and 18), and the air cylinders may be single, or multi-stage. (See Figures 17 and 18.) Again the steam cylinders may be omitted and the power transmitted to the

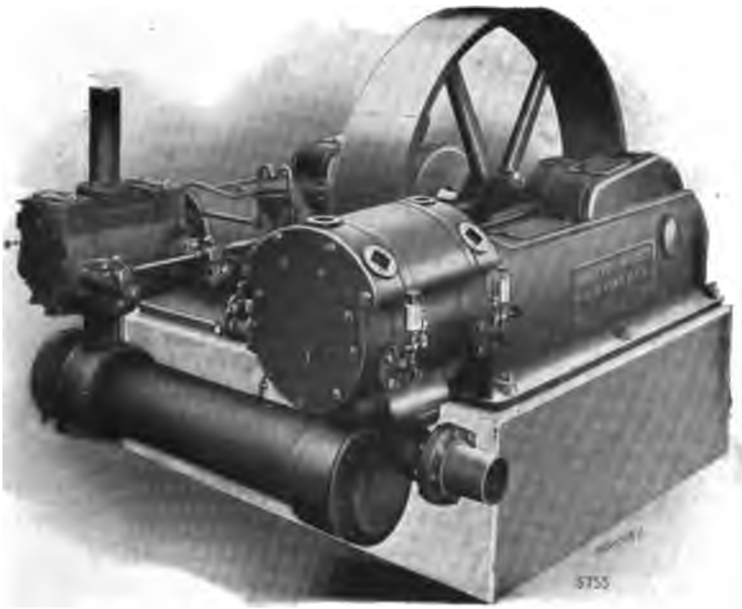

FIG. 19. Duplex, belt-driven, two-stage air compressor.

machine by a belt (see Figure 19) or by a directly connected motor. (See Figure 20.)

TURBO-COMPRESSORS

The turbo-compressor operates upon the principle of a reversed turbine in which air, instead of water or steam, is the fluid acted upon, and it consists essentially of a revolving impeller (not unlike that of some forms of centrifugal fans) surrounded by a set of stationary discharge vanes supported in a suitable casing (see Figure 21). It is the function of the discharge vanes to recover the major portion of the energy which exists in the air as velocity upon leaving the impeller, and which is roughly almost one-half of the total energy supplied from the driving machine, by converting this velocity into available press-

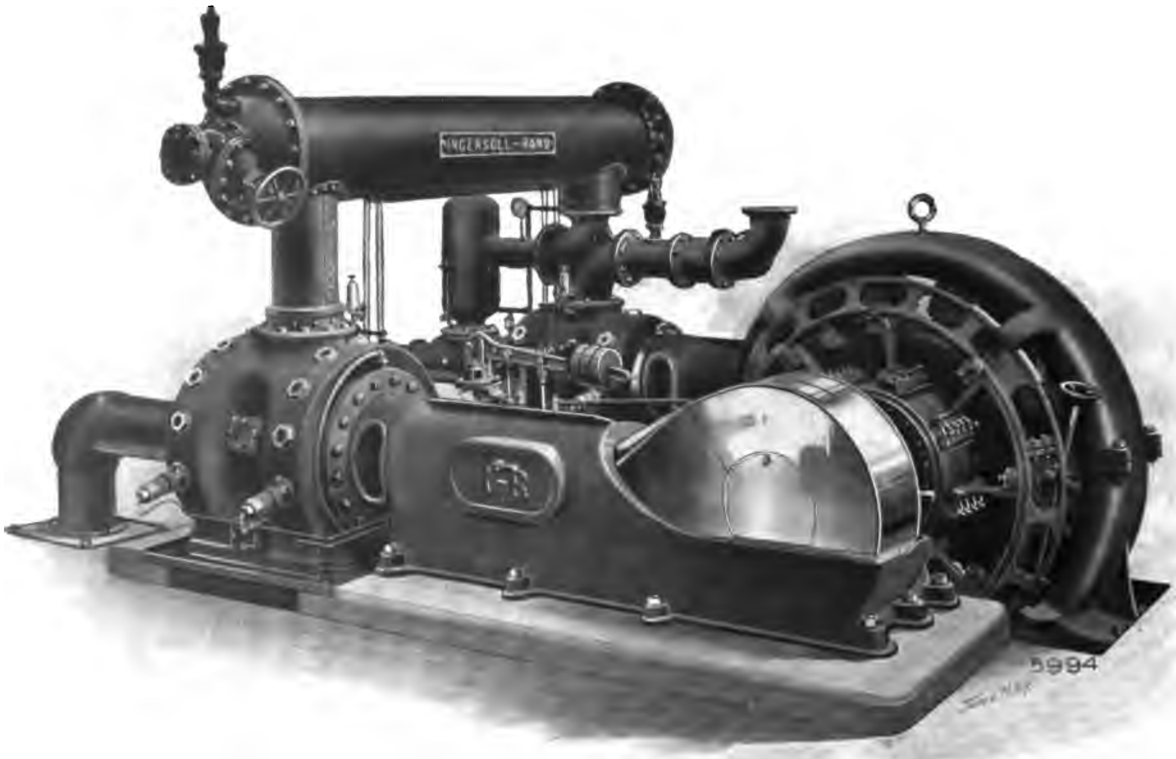

FIG. 20. "Direct-connected," electrically driven, duplex, two-stage compressor.

ure. In the centrifugal fan, there being no such vanes, this energy is lost as heat produced by eddies and friction, hence it is not difficult to see the reasons for the higher efficiency of the new machine. Single-stage turbo-compressors are employed chiefly in connection with blast furnaces, cupolas, etc., and could be used for mine ventilation; but where a high pressure is required, such as that needed for the operation of rock drills and other pneumatic machinery, a number of impeller units are mounted on a common shaft operating in series within a common casing, the air upon leaving the first set of discharge vanes being conducted to the intake of the second impeller, and so on. Compressors producing 170 pounds pressure and having as many as 29 stages have been constructed, but where so many stages are employed the impellers are usually mounted in groups of from four to ten.

The manufacture of turbo-compressors is just beginning in this country, but they have been in use for several years in Germany, where their design and manufacture have already

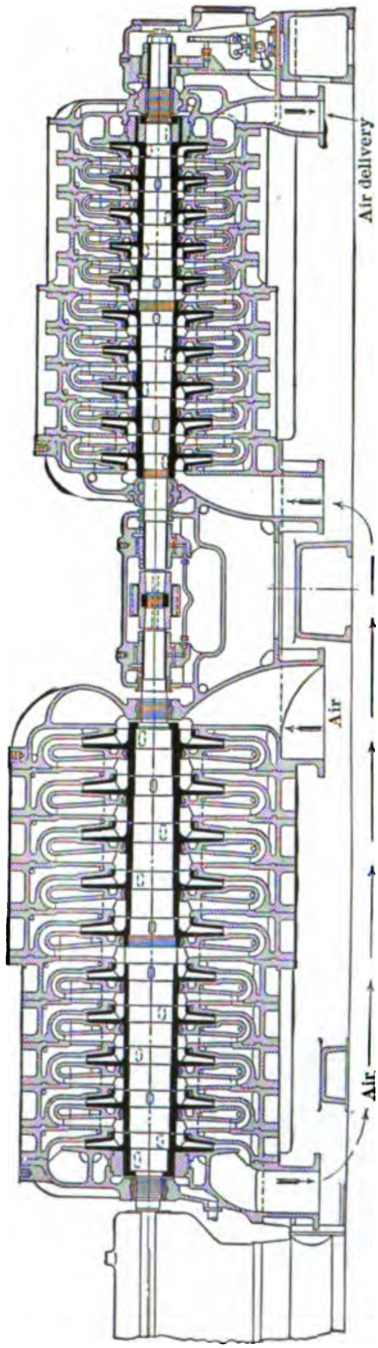

FIG. 21. Section through a turbo-compressor.

reached a high degree of perfection. The first large machine of this kind was built in 1909 for the Reden mines near Swarbrucken. It is driven by 1,000-horse-power, mixed pressure, steam turbine at 4,200 revolutions per minute, and compresses 4,600 cubic feet of free air per minute to a gauge pressure of 90 pounds to the square inch. Quite recently, six motor-driven compressors of this kind were built in Germany for the Rand mines in South Africa. Each of these six machines is operated by two 2,000-horse-power synchronous motors running at 3,000 revolutions per minute. The compressors have a rated capacity of 21,250 cubic feet of free air per minute at 68° F. to 118 pounds pressure per square inch. In a test, when compressing 23,750 cubic feet of free air per minute to 100 pounds pressure, the energy of consumption per hundred cubic feet of free air was 17 horse-power and the highest isothermal efficiency obtained was 67.04 per cent. The first large compressor built in this country went into service in May, 1911, and has been in continuous operation ever since. This machine (figure 22) is driven by a steam turbine at 4,700 revolutions per minute and has a capacity of 3,500 cubic feet of free air per minute delivered at a pressure of 105 pounds per square inch.

It is of course not possible, nor is it within the proper scope of this volume, to describe all the numerous makes of air compressors; for such material the reader is referred to the trade catalogues issued by the various manufacturers, who will be glad to supply this information, and whose experts are prepared to render any assistance possible in the selection of a compressor.

COMPARISONS

The chief advantages of the straight-line compressor are that it is strong, simple, compact, and easily installed. It is usually self-contained, being mounted on a single bed plate, and requires relatively inexpensive foundations. The frictional losses in a good machine of this type are not large and, at or near full load with moderate pressures, it may have a fairly good power economy. These features make it advantageous for less accessible plants or those of a more or less temporary character.

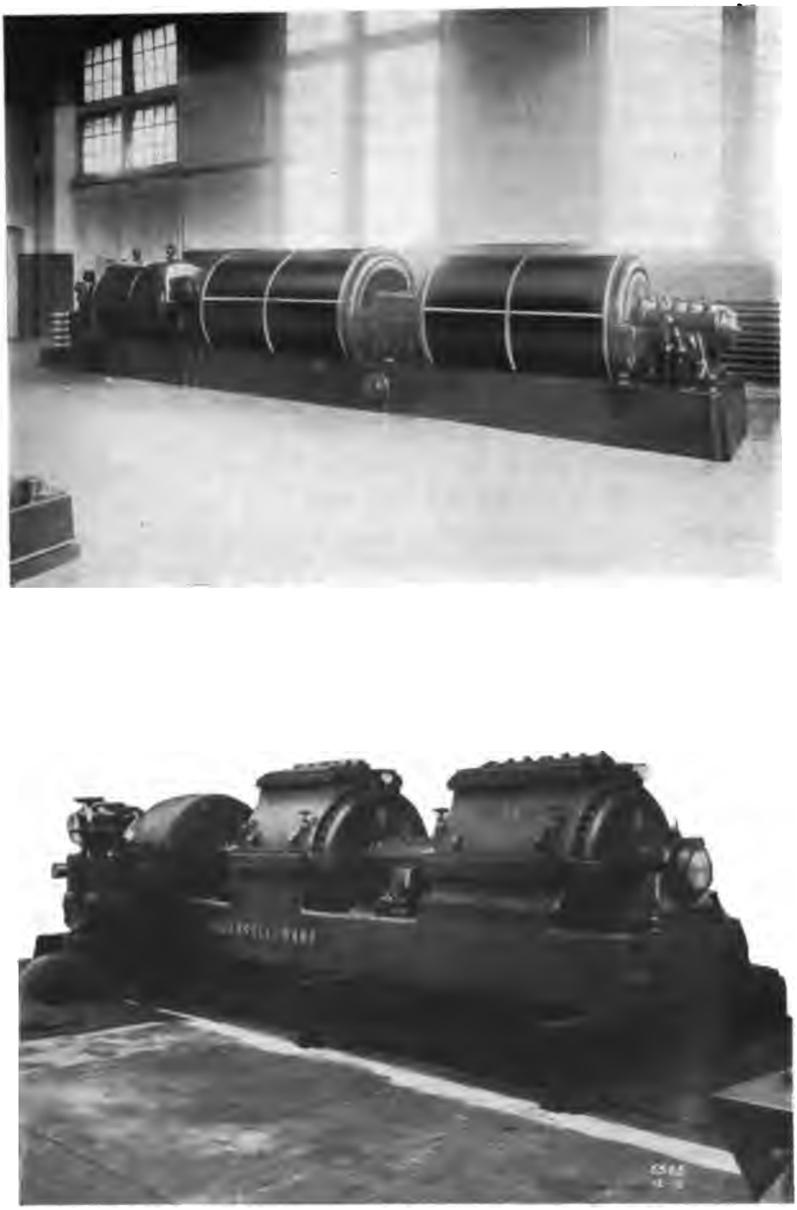

FIG. 22. Turbo-compressors.

A great advantage of the duplex type, on the other hand, is the facility with which either steam or air cylinders may be "compounded" without increasing materially the number of parts. This makes it possible for the duplex type to take advantage of the great saving in power resulting from compound steam cylinders, as well as the economy resulting from two-stage air compression. Practical experience with the two types of machines fully confirms the theoretical investigations of their comparative efficiency, and carefully conducted tests extending over long periods of time have established the economical superiority of the duplex type. In this type, also, if properly designed, the mechanical losses through friction, etc., are but little greater, if any, than in the straight-line compressor, and it is much more easily regulated under varying loads. Most manufacturers are now making duplex compressors with a substantial sub-base, giving the machines a strength and rigidity comparable with the other type, reducing the expense of foundations, thus meeting some of the conditions which have until recently been so much in favor of the straight-line type. The result is that, with perhaps a half-dozen exceptions, the air compressors at tunnel plants examined were of the duplex type.

The entire absence of valves, reciprocating parts, and sliding friction in turbo-compressors, together with their freedom from vibration, their high capacity in proportion to weight and to floor space occupied, and their ability to take advantage of the high rotative speeds of electric motors and steam turbines, are certain to bring these new aspirants for engineering favor into general use. Using live steam, condensing or non-condensing turbine-engine turbo-compressor units are quite able to compete successfully with the very highest grades of reciprocating-engine compressor plants, and they can be operated successfully with exhaust steam from engines, pumps, or other apparatus, which forms one of the cheapest possible sources of power—because in utilizing steam which would otherwise go to waste, practically free fuel is obtained. Another advantage, and one that might easily be overlooked, is the fact that it practically eliminates the danger of explosions in air receivers and pipe lines. In piston

compressors lubrication must be supplied to the inside of the cylinder in order to protect it from the friction of the sliding piston; there is, therefore, every opportunity for the oil (which becomes finely divided in this process) to commingle with the air as it is being compressed and to be carried with it into the receiver. But with the turbo-compressor the only surfaces requiring lubrication are those of the bearings to which the air being compressed has no access. When an electric motor or water-wheel is the source of power, the ease with which the turbo-compressor may be connected to either of them, thereby avoiding all loss due to speed reduction and friction, renders this a most desirable combination. The turbo-compressor is readily adapted to automatic control and may be regulated for the delivery of a constant volume or constant pressure as required. Its efficiency is maintained over a wide range of load within a few per cent. of the maximum, and the efficiency does not decrease with continued service. There is, therefore, every reason to expect that turbo-compressors will come into general use in the near future.

REGULATION

Steam Driven

Although, when steam driven, a change in load with any type of machine results in a variation of speed, this works more to the disadvantage of the straight-line compressor, especially with high air and steam pressure, because this type will not run satisfactorily at low speeds, the momentum of the fly-wheel not being sufficient to carry it past dead centers. To avoid stoppage, either the steam cut-off must be lengthened (in which case there is a loss of steam as the machine speeds up under increasing load) or there must be a fixed limit below which the steam is not decreased, and when the demand for compressed air falls below that supplied regularly by the machine the excess must be permitted to escape through a safety valve. Both of these cases entail loss of power. For this reason the straight-line compressor cannot operate economically much below the limit of 40 per cent. of full load.

In this matter of regulation the duplex, steam-driven machine has an unquestioned advantage over the straight-line machine. The quartered cranks, in addition to minimizing strains and reducing extremes, enable one cylinder to come to the help of the other just at the time when that help is most beneficial, and, a quarter of a revolution later, the favor is returned. There can be no dead center, and the machine will run so slowly as hardly to turn over if the compressed air in the receiver is not being drawn upon, and will speed up rapidly as there is an increased demand for air, doing it without any change in the cut-off. The duplex machine, therefore, has the same steam economy over the full range of load, without any loss of compressed air at the safety valve.

With the turbo-compressor when steam-turbine driven, the regulation is merely a matter of controlling the amount of steam admitted to the turbine.

Water Driven

The regulation of compressors driven by impulse wheels may be accomplished by several methods, among which may be mentioned the deflecting nozzle, the needle nozzle, and the cut-off. The deflecting nozzle is provided with a ball and socket joint and is controlled by air receiver pressure in such a manner that a portion of the stream of water may be shifted on or off the buckets of the wheel, thus increasing or decreasing the amount of power developed to correspond with varying loads. A steel plate may be made to accomplish the same effect by deflecting the stream of water, the nozzle in this case remaining stationary. The needle nozzle is merely a discharge valve in which a conical needle is inserted or withdrawn from an orifice, thus diminishing or increasing the amount of water passing through. The cut-off also regulates the water quantity by a change in the discharge area, produced by the shifting of a plate which fits tightly over the nozzle tip. The deflecting devices are capable of controlling rapid variations in power demand, but are, of course, wasteful of water, while just the reverse is true of the other types. At tunnel plants, however, water economy is rarely an essential consider-

ation while variations in load are frequent and sudden; the deflecting devices are therefore most suitable.

Electrically Driven

The volume of air compressed in any reciprocating machine varies with the number of strokes per minute made by the piston; in the turbine compressor it is dependent upon the rotative speed. In electrically driven reciprocating compressors, whether directly connected or belted to a motor, the speed is necessarily reasonably constant and cannot be varied to meet fluctuating demands for air; and since economy obviously forbids the discharge of excess compressed air through a safety valve, "unloaders" must be provided to overcome the difficulty.

Unloaders.—The more common method is to limit the amount of air admitted to the machine. This type of unloader consists of a valve in the free-air intake pipe controlled by the pressure in the air receiver, which throttles the admission of air when the load is light, and allows more of it to enter when the demand for air increases. This device may be employed successfully with turbo-compressors, but with reciprocating machines it nevertheless has its drawback, because when running with a partially throttled inlet, the smaller amount of air drawn into the cylinder is rarefied and on the return stroke of the piston is consequently compressed through a greater range of pressure, giving rise to higher temperatures than ordinary and they may reach unsafe limits, especially where the terminal pressures are great. This is not so important with turbo-compressors because the temperatures never become so high as they do in reciprocating machines.

On some piston compressors an unloader of almost an exactly opposite type is employed and consists of a device for holding the intake valves open whenever the air pressure reaches a predetermined point.

In one type of unloader for reciprocating machines the excess air is forced automatically into clearance tanks, the process being controlled by a predetermined receiver air pressure. Figure 23 gives a diagrammatic representation of this device. Under normal full load the controller is inoperative, but when working

at partial capacity a portion of the compressed air is forced into the tanks instead of going through the discharge valve, thus reducing the output of the compressor. On the return stroke this air expands, returning its stored energy to the piston. There are eight tanks in all, and four equal and successive unloading stages are possible by throwing in respectively two, four, six, or all of the tanks. The regulation is said to be unaccompanied by shock due to sudden variations in load, and heating

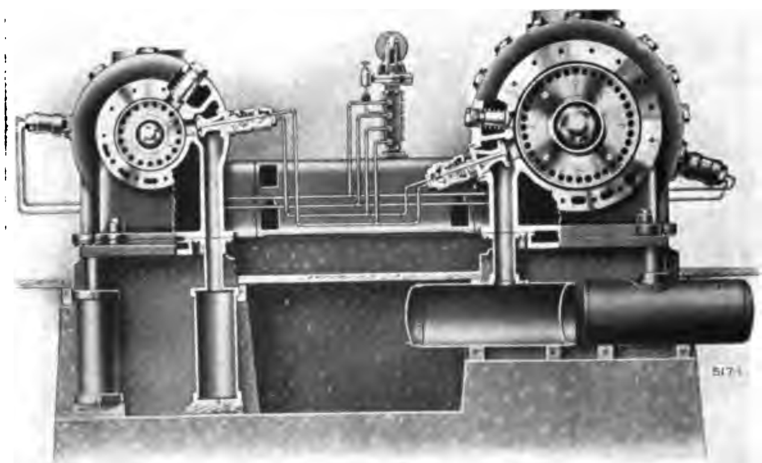

FIG. 23. Diagrammatic cut of clearance controller.

caused by the compression of rarefied air is avoided—in fact, since there is a slight radiation from the clearance tanks, the air is probably returned to the cylinder slightly cooler than when it left.

Another method of unloading is by holding open the discharge valves of the compressor, permitting compressed air instead of free air to fill the cylinder as the piston retreats, and thus balancing the pressure on both sides of the piston. Although this unloads the compressor completely, it has a very serious drawback. As the load is resumed the balance of pressure is disturbed, one side of the piston being subjected to something less

than atmospheric pressure, while the opposite side is exposed to the full pressure of air in the receiver, the difference in pressure being thrown on the piston instantly and maintained throughout the entire stroke. As a result, serious strains are placed upon the structure of the compressor which prohibit the use of this unloader except in the smaller sizes. Still another type releases the partially compressed air during its passage from the low- to the high-pressure cylinders, but little can be said for this method except that it is not quite so wasteful as releasing high-pressure air.

HEAT

Heat Produced

Heat is produced during the compression of air and the rise in temperature is largely dependent upon the difference between the initial and final pressure. For instance, if air at 60° F. be compressed in a single stroke from atmospheric pressure to 100 pounds gauge, the temperature attained would be 485° F., assuming no loss by radiation during the process. On the other hand, under the same conditions, if the final pressure were but 25 pounds gauge, the air would be heated only to 233° F., and if it were then cooled again to 60° and further compressed from 25 pounds to 100 pounds gauge the final temperature would approximately be 250° F. The effect of the increase in temperature is to cause the air to expand to a larger volume, and hence more work is required to compress it. If the air could be used at once to operate a motor, before any of the heat escapes through radiation, etc., this work could be obtained again from the air; but since in mining work the heat is almost without exception entirely dissipated in the pipe line before the air reaches the drills, the production of heat during compression entails a serious loss of power.

Dangers of High Temperatures

Aside from the item of power waste, the temperature reached during compression has an important bearing on the question of

explosions in air lines. It can readily be imagined that if the discharge valves are not working properly and some of the highly heated compressed air is allowed to re-enter the cylinder with the fresh intake air, compression may begin at a temperature much higher than normal, in which case, even with two-stage machines, the final temperature of the compressed air may be gradually built up from 250° to 500°, 600°, or even higher. It is often sufficiently high to volatilize lubricating oil, the vapors of which, mingling with the air, may be in proper amount to form an explosive mixture. If the temperature then becomes high enough to ignite this mixture, an explosion inevitably results. There have been numerous instances where this has actually occurred.

Removal of Heat

The ideal way to prevent the evil effects of heat would be to devise some means of removing it from the air as fast as produced during compression. Such a course is unfortunately impossible of attainment in practice, but various means have been invented which partly accomplish the result. A familiar one is to surround the cylinder with a jacket of cooling water, the piston also being sometimes cooled in this way. But when one considers that air is a very poor conductor of heat and that at the time when it is hottest it occupies but the minimum volume in one end of the cylinder, and even then but for a short space of time, it will readily be seen that this method cannot be very effective. In some modern compressors the inlet valves are placed in the piston and the discharge valves in the ends of the cylinders instead of in the heads, thus permitting the latter to be fully water-jacketed, a practice which is to be most highly commended. As water-jacketing is the only means used to cool the air during single-stage compression, it is not surprising that such machines are not economical of power.

In two-stage compressors, however, a portion of the heat is actually removed during compression. The air is only partially compressed in the first cylinder, perhaps to 25 pounds gauge, and the heat produced is practically all removed during the

passage of the air through an intercooler in its way to the second cylinder, where the final pressure, of perhaps 100 pounds, is attained. By removing the heat in the inter-cooler, the temperature of the air is kept much lower than with single-stage compression, hence there is less expansion of the air to be overcome, resulting in a consequent saving of power. In a properly designed two-stage machine compressing to 100 pounds gauge, this saving of power is approximately 13 per cent., and it increases with the higher terminal pressures. If the pressure is less than 80 pounds, the saving is hardly great enough to be a serious consideration and single-stage machines are customarily employed in such cases, but for pressures higher than 100 pounds two-stage compression is imperative, because of the high temperatures that are otherwise produced. As shown by the following table, the pressure ordinarily employed in tunnel plants ranges from 80–120 pounds, averaging about 100 pounds.

COMPRESSED AIR PRESSURES AT DIFFERENT TUNNEL PLANTS

Carter	112	Marshall-Russell	110	Roosevelt	110
Central	120	Mission	100	Siwatch	80
Gold Links	100	Moodna	95–100	Snake Creek	110
Gunnison	90	Newhouse	110	Stilwell	100
Laramie-Poudre	120	Nisqually	90–95	Strawberry	85
Mauch Chunk	100	Rawley	100	Utah Metals	110
Los Angeles Aqueduct	100	Raymond	90	Walkill	110
Lucania	115	Rondout	100	Yak	90

Because of the many stages required with turbo-compressors when delivering air for use in drilling, the difference between the pressures of the air on entering and leaving any one stage is extremely small compared with that of two-stage reciprocating machines. Hence the resulting increase of temperature in any one step is not great, and it is possible to remove the comparatively small amount of heat generated effectively by the use of a suitably designed water-jacket. Some idea of the efficiency obtainable with such a cooling system may be had from the fact that the air delivered into the receiver at 105 pounds

pressure from the turbo-compressor illustrated in Figure 22, page 95, has a temperature of only 120° F.

INTERCOOLING

The efficiency of two-stage compression is largely dependent upon the intercooler. It is an essential part of this type of machine, and usually consists of a shell, generally cylindrical in shape, containing a number of pipes, similar to those in a tubular boiler, through which cold water is made to circulate. See Figure 24. The heated air from the low-pressure cylinder enters

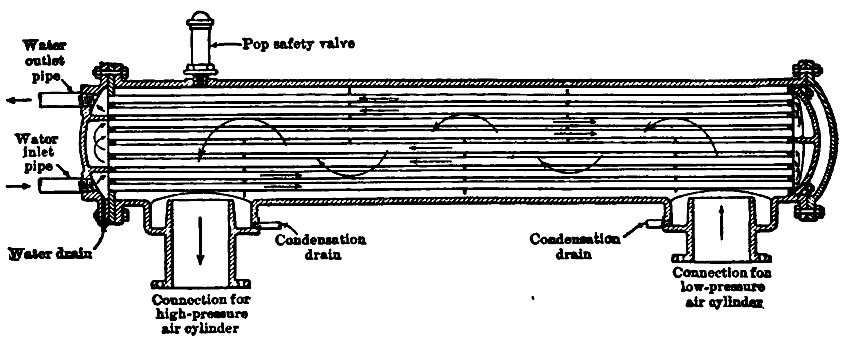

FIG. 24. Typical Intercooler.

near one end, passes through the nest of tubes, its passage being obstructed by baffle plates to insure the maximum contact between air and cooling surface, and is delivered at much lower temperature to the high-pressure cylinder at the other end. The success of the intercooler depends upon several considerations. In order that the least dependence need be placed upon the heat conductivity of the air itself, which is notably poor, the intercooler must subdivide the air completely, and insure that the maximum amount of it is thrown in contact with the cooling surfaces. This is accomplished by properly spaced water-tubes and baffle plates. At the same time the cross-section of the cooler must not be too small, in which case the velocity of the air past the cooling surface would be so great that sufficient time would not be allowed for the water to absorb all the heat.

It is very desirable also to have the water and air flow in opposite directions in order that the final cooling of the air may be effected by the entering, and consequently the coldest, water. Theoretically, the cooling surface should be sufficient to absorb all the heat in the air passed over it, reducing the temperature to the point at which the air entered the low-pressure cylinder, but due possibly to mechanical difficulties, even in good practice, intercoolers usually fail to do this within five or ten degrees, while even 30 or 40 degrees are not unusual.

Moisture

The intercooler assists also in removing water from the air. Normal atmosphere always contains at least some water vapor, but for any combination of relative volume and absolute temperature, air is incapable of absorbing more than a certain amount of water vapor. This maximum at 60° F. and 14.7 pounds pressure is .0137 ounce, while under the same pressure and at 32° F., air can hold but .0046 ounce and at 0° F. but .0011 ounce. In the air compressor both of these factors of volume and temperature are suddenly and violently disturbed. The water vapor in the air would be released were it not for the fact that as the volume is reduced (a process which would ordinarily decrease the capacity of the air for moisture) the temperature is greatly raised at the same time, increasing the water-carrying capacity of the air; the increase in capacity for moisture, caused by the high temperature, being greater than the decrease due to reduced volume and no water is precipitated. But as the air passes through the intercooler the temperature is lowered greatly without a corresponding increase in volume, and the air is forced to give up its water. It is precipitated in such a finely divided state, however, that it requires some time to settle; for that reason only a portion of it can be collected in the intercooler and drawn off through drains provided for that purpose, the remainder being swept along with the air to the higher-pressure cylinder and revaporized by the temperature there attained.

ACCESSORIES

Precoolers

Cooling the air before its admission into the air compressor also assists in removing some water from it, and there are a number of devices for this purpose. One precooler described in the *Engineering and Mining Journal* * is a home-made affair consisting simply of a number of odd pipes set between two wooden boxes. The pipes are wrapped with cloth and water is arranged to drip on them constantly, so that the air is cooled by evaporation as it is drawn through them from one box to the other on its way to the compressor intake. At a plant in Johannesburg the air for the compressors is obtained through a subway leading to the center of a building with air-tight roof and floors, and with walls consisting of constantly wetted cocoa matting. At another plant a similar structure was used in which the sides and roof were covered with burlap both inside and out. A cooler of this type also filters dust and grit which might seriously injure the cylinder or piston of the compressor, and cannot be too strongly recommended in dusty situations. Precooling the air also increases the capacity of the compressor, because the cooler air occupies less space than when it is heated, hence a larger actual amount of air will be drawn into the cylinder and compressed at each stroke.

After-cooling

The after-cooler,† although it is not generally employed in tunnel plants, by cooling the air at once after it comes from the high-pressure cylinder, also precipitates some of the water vapor, but at the same time it reduces the volume of the air and practically eliminates the danger of explosion in the air line. Although the air gives up its water vapor in the cooler because of the de-

* November 27, 1909, p. 1081.

† In design and principle the after-cooler is practically the same as an intercooler, and it is usually placed between the compressor and the air receiver.

crease in temperature, it is usually in so finely divided a state that all of it does not at once fall out, part being swept along with the air and deposited both in the air receiver and in the pipe line. There should, therefore, be provision for draining this water at some low point. The amount of the reduction in volume is somewhat speculative and probably not a serious consideration.

AIR RECEIVERS

The air receiver,* according to the popular notion, is supposed to perform the functions of storing, cooling, and drying air, together with equalizing irregularities in its production and use, but it is more than probable that in actual practice it accomplishes these results, with the exception perhaps of the last one, very inefficiently. When one takes into consideration the fact that the receiver ordinarily installed in tunnel plants rarely has a capacity greater than one minute's run of the compressor, it will be seen that it cannot possibly furnish any great amount of storage space. Then, too, since the air in the receiver is being renewed each minute when the compressor is in operation the velocity of the air through the receiver must be enough to prevent any great amount of cooling. There will, of course, be some radiation of heat from the air near the shell, but this is small compared to the heat in the mass of the air in the center of the receiver, so that the air leaves with a temperature but slightly lowered, if at all, below that at which it entered. And furthermore, since there is practically no cooling of the air, there can be no great precipitation of water vapor. As a matter of fact this is the case in practice, for, although most air receivers are provided with a drain of some sort, only a ridiculously small amount of water is ever drawn off. On the other hand, instead of cooling, the air receivers have actually in some instances become combustion chambers. Oil and grease in time collect on the inside of the shell and may become ignited if the temperature of the air becomes high enough. Together with the pipe

* The air receiver consists simply of a cylindrical shell of steel provided with inlet and outlet pipes and usually a safety valve.

line, which storage space may be considered as an auxiliary, the receiver does assist greatly, however, in equalizing the pulsations not only of the air delivered from the compressor but also of that used by the drills, and in this way it reduces strain on the structure of the compressor. By regulating the flow, it does not permit the air to attain a high velocity in the pipes even irregularly, and hence power is saved since the friction losses increase greatly with the velocity. To secure the maximum benefit from this factor, a second receiver is often installed as near as possible to the place where the air is to be used. In this case the second receiver assists materially in maintaining a steadier air pressure at the drills. A tubular boiler, which it is often possible to buy cheaply at second-hand, makes an excellent receiver and a very efficient cooler. With a vertical tubular boiler it is only necessary to remove the fire and ash doors to provide for ventilation, while a horizontal tubular boiler should be placed on an incline sufficiently steep to insure a rapid draft of outside air through the flues.

Drains

Since practically the entire cooling of the air after leaving the compressor takes place in the pipe line, it is here that most of the water is precipitated and causes serious inconvenience in several ways. During cold weather, through continued deposition and freezing, the pipe line may become closed altogether or so restricted as to cause serious drop in pressure or loss of power. Or the water getting into the exhaust from the drills not uncommonly prevents their operation through freezing at the low temperature of the expanded air. The obvious remedy is to remove the water, which is done by draining the low places in the line where the water collects. This can be accomplished automatically by the use of any good float design steam trap, but where the pipe is exposed to low temperatures the trap should be placed in a small pit or otherwise protected to prevent freezing. Where necessary, further provision for the elimination of moisture from the compressed air and water from the pipes

can be had by placing in the line any high-class standard steam separator, fitted with an automatic trap as described above.

CONCLUSIONS

In conclusion, let us sum up briefly the factors which enter into the problem of selecting an air compressor. The power required for both reciprocating and turbine machines is approximately 18 to 20 brake horse-power for every 100 cubic feet of free air compressed to 100 pounds gauge. The values given in trade catalogues for reciprocating compressors are generally a little below this figure, but it is a safe one to use in estimates. Such compressors ordinarily have a volumetric efficiency of approximately 80 per cent., and since they are rated on the basis of free air and since it is necessary to make allowance for loss due to clearance, etc., provision for increased air consumption above the catalogue rating for drills as they become worn, and for that used in sharpening machines and forges, must also be made with either reciprocating or turbine machines, and it is advisable to select an air compressor considerably oversize. In practice the amount of oversize, based upon drills only, ordinarily ranges from 100 to 150 per cent. Of the two types of reciprocating compressors the duplex is preferable to the straight line (in spite of the latter's simplicity and easier installation) because of the former's more economical and efficient use of power and the facility of its regulation, especially when steam driven and with high pressures. Since the air pressure at tunnel plants is rarely below 80 pounds, and in three out of every four it is 100 pounds or greater, two-stage compression is desirable because of its economy of power, if not indeed imperative because of the air temperatures that might otherwise be attained. Although the manufacture of turbo-compressors is just beginning in this country, they possess a number of advantages, especially for use with steam turbines and other rotary engines operating at high speeds, which will doubtless lead to their more general use in the future. Their development should therefore be closely watched. Steam-driven compressors

are regulated by varying their speed; but since in some power-driven machines the speed is necessarily constant, other means, of which the throttle inlet and the clearance controllers are the two most used, must be provided for that purpose. Heat is produced during compression and by expanding the air causes loss of power. Some of this loss is obviated in two-stage compression by removing the heat during its passage through an inter-cooler between the cylinders. The numerous stages in the turbine machine enable this heat to be removed effectively by water-jacketing in this type of compressor. Another evil attributable to this heat is the danger from the explosion of volatilized lubricating oils; but in the turbine machine this danger is eliminated because there are no sliding surfaces to require lubrication. Among the accessories which are designed to prevent or neutralize the effects of heat in piston machines are the pre-cooler, the intercooler, the after-cooler, and the air receiver. The last mentioned also equalizes the pulsations of the air and reduces friction losses. These devices assist, too, in freeing the air from water, which often causes serious inconvenience. The major portion of the water is deposited in the pipe line, however, where provision must be made for its removal.

CHAPTER VI

VENTILATION

MACHINERY

EITHER blowers or fans are employed ordinarily for ventilating tunnels and adits. In machines of the first type, a certain amount of air is trapped every revolution between the impellers and the enclosing casing, and has no means of escape (to omit from consideration a small amount of leakage) except through the exhaust pipe (see Figure 25). For this reason they are

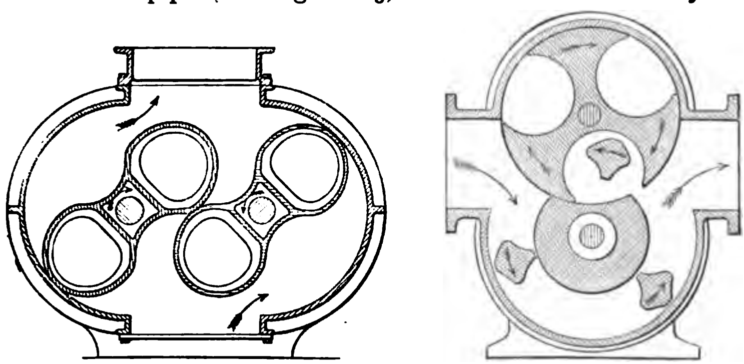

FIG. 25. Diagrammatic cross-sections illustrating the action of pressure blowers.

often styled "pressure" blowers and "positive blast" machines. Figure 26 shows one of these blowers in operation on the Los Angeles aqueduct.

Where fans are employed in tunnel ventilation they are, almost without exception, centrifugal—the familiar propeller form similar to the ordinary desk fan being rarely used. In the centrifugal fan the air enters near the center, traveling in a direction approximately parallel to the axis of the shaft, and is forced by the centrifugal action of the rapidly revolving blades toward their periphery, where it is collected and discharged. There are many modifications of this design, with the intention of preventing loss of efficiency through friction as the air strikes

the back plate and changes direction, or to prevent eddies, etc., due to the greater density of the air at that point caused by its momentum upon entering the fan.

Turbo-compressors in which, by the adoption of one or two or even several stages, air can be delivered at any required pressure, have been employed as blowers for blast-furnace and foundry work at a number of places. The capacities of those manufactured for this purpose thus far are too great for the requirements of tunnel work, but their greater efficiency as

FIG. 26. Ventilating blower used on Los Angeles Aqueduct.

compared with centrifugal fans and the possibility of designing them to secure any required pressure will doubtless soon lead to their being made in sizes suitable for tunnel work, where they should have a large field.

At one tunnel a certain amount of vitiated air was removed from the heading by the use of a jet of highly compressed air which was directed into the ventilating pipe; but this method, in addition to being expensive, is inadequate as well, and is, therefore, not to be advised, except as a temporary expedient and for short distances. On short levels and cross-cuts, however, or on larger work pending the installation of more expensive and efficient machinery, jet blowers can often be used to good

advantage. They can be operated by either compressed air or water under pressure, and, while far from being as efficient as the mechanical types of ventilating machinery, will in many cases perform an extremely useful function. Jet blowers can frequently be used with good results to move large volumes of air for short distances against low frictional resistances, and their extreme economy in first cost makes them an excellent accessory in preliminary work.

DIRECTION OF CURRENT

The fan or blower ordinarily installed for tunnel work may be made, by a proper adjustment of the ventilating pipe, to exhaust the air from or deliver it to the heading. One of the chief advantages of the first method is that the dangerous gases and smoke produced in blasting are promptly removed from

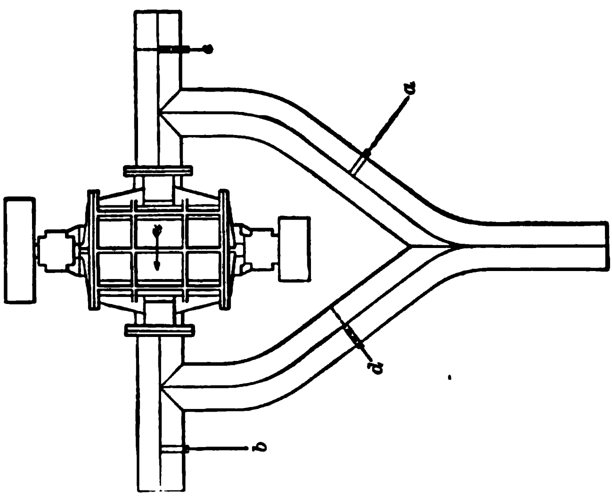

FIG. 27. Arrangement of gates and pipe for changing direction of ventilating current.

the tunnel, and it is therefore unnecessary for the workmen to pass through a thick bank of smoke which would otherwise travel very slowly to the portal. On the other hand, when fresh air is blown in, it passes very much faster through the pipe and is cooler and fresher than if it had worked its way slowly in through

the tunnel or adit and become heated from contact with the walls and contaminated by odors from the track; the men, therefore, feel more comfortable and are able to do better work when this method is employed. The advantages of *both* methods, however, may be readily obtained by an arrangement of pipes similar in principle to the one shown in Figure 27, which permits the air to be exhausted for a few minutes after blasting, by opening gates *a* and *b* and closing *c* and *d* (assuming the current through the fan or blower to be in the direction of the arrow), while at other times, by reversing this arrangement, air may be forced into the heading. The following table shows the direction of the air current at various tunnels visited, from which it may be seen that, almost without exception, it is customary to exhaust the smoke, after blasting at least, although at many places the ventilating current is reversed at other times. This arrangement is reported as giving excellent results, and its use is strongly recommended.

DIRECTION OF AIR CURRENT AT VARIOUS TUNNELS

Tunnel	Ordinarily	After Shooting
Carter	Exhaust	Exhaust
Central	Exhaust	Exhaust
Gold Links	Exhaust	Exhaust
Gunnison, East Portal	Exhaust	Exhaust
Gunnison, West Portal	Blast	Exhaust for two hours
Laramie-Poudre	Exhaust	Exhaust
Lausanne	Blast	Blast
Los Angeles Aqueduct,		
Elizabeth Lake	Blast	Exhaust 20–25 minutes
Little Lake	Blast	Exhaust for one hour
Grapevine	Blast	Exhaust ½ to 1 hour
Lucania	Exhaust	Exhaust
Marshall-Russel	Exhaust	Exhaust
Mission	Blast	Exhaust ¾ to 1 hour
Newhouse	Exhaust	Exhaust
Nisqually	Exhaust	Exhaust
Rawley	Exhaust (Intermittently)	Exhaust
Raymond	Blast	Exhaust for two hours
Rondout	Blast	Exhaust "for a while"
Roosevelt	Exhaust	Exhaust
Siwatch	Exhaust	Exhaust
Snake Creek	Exhaust	Exhaust
Stilwell	Exhaust	Exhaust
Strawberry	Exhaust	Exhaust
Utah Metals	Exhaust	Exhaust
Walkill	Blast	Exhaust
Yak	Exhaust	Exhaust

CAPACITY

There is unfortunately no authoritative rule for determining the amount of air needed to renew that vitiated by the respiration of men and animals working in tunnels. For coal mines many States have provided a legal minimum which ranges from 100 to 300 cubic feet per minute for each man and from 300 to 600 cubic feet for each animal. These figures, however, have practically no bearing on tunnel work, because in coal mines a much larger volume of air than that actually needed by the men must be supplied in order to dilute and render harmless the inflammable and dangerous gases given off from the coal. In many States the laws provide that even these requirements must be increased at the discretion of the mine inspector. Conditions in metal mines, on the other hand, are more closely akin to those in tunnels, but, unfortunately, wherever any legislation exists at all it merely stipulates that the ventilation must be "adequate."

Robert H. Richards considers that the following air quantities are sufficient for proper ventilation in metal mining work:*

Per light, 1 cubic foot per minute.
Per man, 25 cubic feet per minute.
Per animal, 75 cubic feet per minute.

The Mining Regulations Committee of the Transvaal, on the other hand, provide (for metal mines) a minimum of 70 cubic feet per man per minute.† When a person is sitting in repose as in a theater or meeting-hall, 20 cubic feet of fresh air per minute is considered adequate provision by engineers making a specialty of ventilation, but much larger quantities are of course required when working. The following table giving the results of a test, conducted by Bernhardt Draeger,‡ shows the amount of air breathed in the first minute after performing various kinds of work.

* "Mining Notes." Richards, Robt. H., Vol. II, p. 142. Thos. Todd, Boston, 1905.

† *Eng. and Min. Jour.*, November 5, 1910, p. 899.

‡ *Glückauf*, 1904, No. 42.

QUANTITY OF AIR ACTUALLY BREATHED IN FIRST MINUTE AFTER EXERTION

Kind of Work	Subject A	Subject B	Subject C	Average
Sitting 10 minutes	8.5 liters	8.25 liters	9.0 liters	8.58 liters*
Walking 270 yards	10.5 "	11.3 "	11.7 "	11.2 "
Marching 550 yards	14.3 "	17.5 "	13.0 "	14.9 "
Running 270 yards	30. "	30. "	30. "	30. "
Rolling barrel weighing ¾ cwt	38. "	33. "	40.5 "	37.2 "
Running 550 yards	38. "	42. "	38. "	39. "
Race, 270 yards	52. "	61. "	59. "	51. "
Time of race	40 secs.	42 secs.	42 secs.	41 secs.

* 1 liter = 0.0353 cu. ft.

These figures give the amount of pure air actually exhaled and inhaled, but of course, in order that the products of respiration may be diluted sufficiently for the air in the confined space of a tunnel to be kept pure, a much larger quantity than this must be supplied. Assuming that 20 cubic feet is sufficient for a man at rest, and applying the ratio deduced from Draeger's table, it would appear that the following volumes of air should be supplied for ventilation if the same exercise were undertaken in a small room or in a tunnel:

VENTILATION REQUIRED WHEN EXERCISING IN A RESTRICTED SPACE

Sitting, 20 cubic feet per minute.
Walking, 26 cubic feet per minute.
Marching, 35 cubic feet per minute.
Running, 70–90 cubic feet per minute.
Rolling barrel, 85 cubic feet per minute.
Race, 130 cubic feet per minute.

Although some members of the tunnel crew, such as the shovelers, ordinarily work as hard as men running or rolling a barrel, the work of the drillers as a rule more closely approximates the exertions required in walking; so, taking everything into consideration, it would seem that 75 cubic feet per minute should be adequate provision for tunnel ventilation, as far as the requirements of human respiration are concerned. Assuming that an animal requires two to three times the air needed for a person, on this basis 150 to 200 cubic feet per minute

should be furnished each of them. At mine tunnels where any attempt is made for even moderate progress, from 8 to 15 men, and possibly two animals, are employed in or near the heading. Under these conditions 600 to 1,500 cubic feet of fresh air per minute would be required for purposes of respiration. It is true that some air is furnished by the exhaust from the drills, but their action is intermittent and the supply never adequate, so that much dependence cannot be placed upon it; on the whole, it is much better simply to ignore this possible source when deciding upon the capacity of ventilating machinery.

Although the above capacity is sufficient for ordinary requirements, a much greater, and indeed the maximum, demand for ventilation occurs immediately after blasting, when it is obviously important to remove the gas and smoke quickly so that the men may resume work with the least loss of time. The volume to be removed depends largely upon the amount of explosive employed; for customary charges under normal conditions it would probably not vary greatly from 60,000 cubic feet, the average result of practical experience at tunnels where information bearing on this question was obtainable. It is true that ordinarily the air is seldom contaminated by the blast for more than 150 feet from the face, which in a heading of 70 square feet cross-section would have a volume of but 10,500 cubic feet, and it might appear that the removal of this amount of bad air would clear the tunnel. Such might be the case provided the smoke could be removed instantly, but this is of course not attainable in practice. The readiness with which gases become diffused must be taken into consideration, especially in this case, since it is customary, immediately after blasting, to turn a jet of highly compressed air into the heading. Such a practice is necessary because, to avoid injury from flying rock, the ventilating pipe rarely extends nearer the breast than 100 feet, so to remove the gases they must be forced out of the extreme end of the tunnel into the influence of the suction of the ventilating pipe. The result is that as a portion of the bad air is removed its place is occupied by fresh air, which quickly becomes contaminated, and it is necessary, therefore, to remove

nearly six times the amount of foul air to clear the tunnel. In order to be considered good practice, under ordinary conditions this should be done in fifteen minutes, requiring an exhauster capable of removing 4,000 cubic feet per minute.

This capacity, however, is necessary for only a few minutes after blasting. It is desirable therefore to have the fan or blower so arranged that it can exhaust for a short time at full load and then be run at a lower speed and supply the heading with the smaller volume needed for respiration. Such was the case at the Laramie-Poudre tunnel, where the exhauster was directly connected to a water-wheel and commonly removed approximately 1,300 cubic feet running at 100 r. p. m. But immediately after blasting the blower was speeded up to 300 r. p. m. when it exhausted nearly 3,900 cubic feet per minute, clearing the heading usually in 15 to 20 minutes.

At the Rawley tunnel an attempt was made to secure the same result by operating the blower intermittently at or near full load. Although the operation of the blower or fan at full load for one-third of the time supplies the heading with an equal amount of air as when running at one-third capacity all the time, different results are obtained in practice. The purity of the air is not maintained so nearly constant with the intermittent system, and since the starting and stopping of the blower are usually dependent upon some man, they are apt to be forgotten or neglected. This method of ventilating, therefore, cannot be commended.

PRESSURE

It is, of course, essential that the required amount of air be actually delivered to, or removed from, the heading; to do this, pressure is necessary in order to overcome the frictional resistance to the flow of air in the pipe. This pressure must be generated by the fan or blower and may be either positive, when forcing air in, or negative, when exhausting it; in either case the amount required depends upon the quantity of air passed and the size and length of pipe. Although the relations between these several factors are somewhat complicated, they

are shown in the following formula advocated by George S. Hicks, Jr.:

$$q = 44.72\, d^{\frac{5}{2}} \sqrt{\frac{(P^2 - 14.7^2)}{l\, g}}$$

Where q = quantity of air in cubic feet per minute.
d = diameter of pipe in inches.
P = absolute initial pressure in pounds per square inch.
l = length of pipe in feet.
g = specific gravity of gas referred to air as unity.

From which we obtain by transposing:

$$p = \sqrt{216.10 + \frac{q^2\, l}{2000\, d^5}} - 14.7$$

Where p = $P - 14.7$, or the required pressure in pounds per square inch,
g = 1.

It must be borne in mind that the formula is theoretical and does not take into consideration leakage, the extra friction due to elbows in the pipe, etc., but it is said to be based on good general practice for air and gas transmission and to give fairly satisfactory results. The following table, calculated from the formula, shows the pressure, in pounds per square inch, required to pass air through various sizes and lengths of pipe, assuming its quantity to be 4,000 cubic feet per minute (the value derived above as a suitable maximum capacity for a ventilating blower or fan).

Loss of Pressure, in Pounds per Square Inch, When Forcing 4,000 Cubic Feet of Air per Minute Through Various Lengths and Sizes of Ventilating Pipe

Diameter of pipe, in inches	Length of Pipe in Feet									
	1,000	2,000	3,000	4,000	5,000	6,000	8,000	10,000	12,000	14,000
6.....	20.2	.....	....	....	.....	....	....	....	....	....
8.....	6.75	11.8	....	....	.....	....	....	....	....	....
10.....	2.52	4.69	6.65	8.45	10.1	....	....	....	....	....
12.....	1.06	2.05	2.90	3.87	4.71	5.52	7.06	8.63	9.87	....
14.....	0.50	0.98	1.45	1.90	2.32	2.77	3.60	4.40	5.16	5.90
16.....	0.26	0.51	0.76	1.02	1.25	1.48	1.95	2.40	2.84	3.27
18.....	0.14	0.29	0.43	0.58	0.70	0.84	1.11	1.38	1.64	1.89
20.....	0.085	0.17	0.25	0.34	0.42	0.50	0.67	0.83	0.99	1.15

If the pressure cannot be increased to correspond with the length of pipe, the volume of air delivered is diminished (the size of the pipe remaining the same). This is illustrated in the following table in which a maximum pressure ($P-14.7$) of one pound per square inch is assumed.

MAXIMUM AIR CAPACITIES IN CUBIC FEET PER MINUTE OF PIPES OF DIFFERENT SIZES AND LENGTHS WHEN THE INITIAL PRESSURE IS ONE POUND PER SQUARE INCH

Diameter of pipe, in inches	Length of Pipe in Feet									
	1,000	2,000	3,000	4,000	5,000	6,000	8,000	10,000	12,000	14,000
6.....	685	485	....	....	....	....	....	....	....	....
8.....	1410	1000	815	705	630	575	....	....	....	....
10.....	2465	1745	1425	1235	1105	1005	870	780	710	660
12.....	3890	2750	2245	1945	1740	1590	1375	1230	1125	1040
14.....	5720	4045	3300	2860	2560	2335	2020	1810	1650	1530
16.....	7985	5645	4610	3990	3570	3260	2825	2525	2305	2135
18.....	10,720	7580	6190	5360	4795	4375	3790	3390	3095	2865
20.....	13,950	9865	8055	6975	6240	5695	4930	4410	4025	3730

The following table shows the calculated pressure required to overcome frictional resistance in passing a volume of air

PRESSURE REQUIRED TO FORCE AMOUNT OF AIR EQUIVALENT TO CATALOGUE RATING OF VENTILATING MACHINE TO PROPOSED LENGTH OF TUNNEL THROUGH PIPE CHOSEN

Tunnel	Rated capacity, cu. ft. per minute	Diameter vent. pipe, inches	Stated length of vent. pipe when tunnel is completed	Pressure required, in lbs. per sq. in.
Carter.....................	1560	15	7600	0.41
Central....................	5540	19	9500	1.93
Laramie-Poudre.............	3900	14½	9200	3.34
Los Angeles Aqueduct:				
Elizabeth Lake...........	6350	18	13000	4.14
Little Lake..............	2500	12	3000*	1.23
Grape-Vine...............	2500	12	1500*	0.63
Lucania....................	3120	18½	12000	0.87
Marshall-Russel............	4160	12½	11000	8.30
Mission....................	2500	10	13000	10.25
Nisqually..................	2400	14	5000	0.87
Rawley.....................	2500	12½	6200	2.02
Roosevelt..................	4800	16½	15700	4.38
Siwatch....................	1560	10	5000	1.94
Snake Creek................	4650	16	14000	4.27
Strawberry.................	4000	14	19000	7.50
Utah Metals................	4880	12	11800	13.24

* This division contains a number of tunnels. The distance given is the maximum.

equal to the rated capacity of the ventilation machine, through pipes of the sizes adopted, to the headings of some of the tunnels visited in the field work.

It will be observed in these examples that the pressures needed ordinarily range from 1 to 5 pounds, 2 pounds being roughly the average. At two of the tunnels in this list, in order to secure the extra pressure required to furnish sufficient ventilation, it was necessary to use a "booster," as it is called; that is, to install a second machine some distance within the tunnel and by operating both together virtually doubling the pressure otherwise attainable. At the Mission tunnel, the booster was situated near the 5,500-foot station. At the Strawberry, both machines had been placed in the tunnel at the time of examination, the first one at 4,000 feet and the second at 11,000 feet. Two other tunnels had not penetrated far enough at the time visited to require such additional equipment, but doubtless extra provision for obtaining pressure will become necessary with continued progress.

SIZE OF PIPE

The necessity for high pressures (and hence the use of boosters) may be obviated in large measure by the choice of ventilating pipe having diameters of sufficient size. The difference between a 12-inch and an 18-inch pipe often exerts a great influence on the ventilation of the heading, but even aside from added cost, indiscriminate enlargement is undesirable, every inch of space in the average tunnel being jealously required for other purposes.

By transposing formula (1) we obtain

$$d = \sqrt[5]{\frac{q^2\, l\, g}{2000\,(P^2 - 14.7^2)}}$$

which gives the necessary diameter of the pipe in terms of the other variables. The following table shows a number of solutions of this formula (assuming again that $q = 4{,}000$ cubic feet per minute to be passed) and from it may be found the proper size of pipe for use with various pressures and distances.

Diameter of Pipe in Inches, Required in Order to Deliver 4,000 Cubic Feet of Air per Minute with Different Initial Pressures and for Various Distances

Pressure	Length of Pipe in Feet									
	1,000	2,000	3,000	4,000	5,000	6,000	8,000	10,000	12,000	14,000
1 oz.	21¼	24¼	....	....	....	....	....	....	....	....
2 "	18½	21¼	23	24¼	....	....	....	....	....	....
3 "	17	19½	21¼	22½	23½	24½	....	....	....	....
4 "	16¼	18½	20	21¼	22¼	23	24½	....	....	....
5 "	15½	17¾	19¼	20¼	21¼	22	23½	24½	....	....
6 "	15	17	18½	19½	20½	21¼	22½	23½	24½	....
8 "	14	16¼	17½	18½	19¼	20	21¼	22¼	23	23¾
10 "	13¼	15¼	16¾	17¾	18½	19¼	20¼	21¼	22	22¾
12 "	12¾	14¾	16	17	17¾	18½	19½	20½	21¼	21¾
1 lb.	12¼	14	15¼	16	16¾	17½	18½	19¼	20	20¾
1½ "	11¼	13	14	14¾	15½	16	17	17¾	18½	19
2 "	10¼	12¼	13¼	14	14½	15	16	16¾	17¼	17¾
3 "	9½	11¼	12	12¾	13¼	13¾	14¾	15¼	15¾	16¼
4 "	9	10½	11¼	12	12½	13	13¾	14½	15	15½
5 "	8¾	10	10¾	11¼	11¾	12¼	13	13½	14	14½
6 "	8¼	9½	10¼	11	11½	11¾	12½	13	13½	14
8 "	7¾	9	9¾	10¼	10¾	11¼	11¾	12¼	12¾	13¼

COMPARISON OF FANS AND BLOWERS

Within certain limits, the speed at which fans are operated determines the volume of air delivered and the pressure generated, but these machines are incapable of producing pressures much greater than 1¼ pounds per square inch, and many of them are limited to 8, or even 5, ounces. Therefore, as the frictional resistance against which air is to be forced or exhausted becomes greater through increasing lengths of pipe, the pressure generated in the fan must be increased (by greater speed) to the maximum limit at which the fan may be operated, and after that is passed, the volume of air delivered necessarily becomes diminished. The blower, on the other hand, is capable of much higher pressures, 8 pounds per square inch being easily attainable, while with some makes 15 pounds is possible, and in tunnel work where distances are, as a rule, great, the ability to deliver air against high resistance is an important consideration in favor of the blower. It operates also at a much lower speed when delivering the same volume of air against an equal pressure (1 : 10 is con-

sidered a fair ratio), and this lessens the wear and tear upon belts and machinery. Because of its higher pressure, the blower makes it possible to choose a smaller diameter of pipe, a factor worthy of consideration, since not only the initial cost, but also the space occupied, must be taken into consideration. The first cost of the fan, on the other hand, is less than that of the blower, and to economize room and obviate the wear on the belt it may be connected directly to electric motors, the greater cost of low-speed motors tending to prevent this possibility with a blower.

CONCLUSION

In most cases a machine of the blower type, capable of high pressure, is better adapted for tunnel ventilation where resistances are apt to be great. For best results the ventilating pipe should be so arranged that the direction of the air current may be alternated at will, exhausting for a short time after shooting, and blowing for the remainder of the time. The blower should be adjusted to operate at two capacities: a lower one supplying 600 to 1,500 cubic feet per minute as determined by the number of men and animals, and a higher one capable of exhausting approximately 4,000 cubic feet per minute, which would make it possible, under ordinary conditions, for the men to resume work in the heading about fifteen minutes after shooting. The pressure generated in the blower must be properly adjusted to the size of the pipe and the length of the tunnel in order that the determined volume of air shall be actually delivered to or removed from the heading. The pipe chosen should be of such size that only a moderate pressure at the blower is required, at the same time due consideration being accorded such items as cost of pipe, and the space such pipe must occupy.

Turbo-compressors, however, which are especially suited for high rotative speeds of electric motors, making it easily possible to connect the two directly without loss due to speed reduction, which are capable of maintaining a high efficiency (nearly double that of the centrifugal fan and fully equal to, if not greater than, that of the blower) even after long service, and which may

be designed by using a proper number of stages to deliver air against any given resistance, will deserve serious consideration, as soon as they are made in suitable sizes, as a possible choice for ventilation machinery.

CHAPTER VII

INCIDENTAL SURFACE EQUIPMENT

In connection with the blacksmith and repair shops, mention should be made of the drill-sharpening machine and the compressed-air meter. The use of the former is quite common, being employed at a majority of the tunnels visited; but the latter, so far as could be learned, has been used only in one or two places, although there appears to be a field for its employment in tunnel plants.

DRILL-SHARPENING MACHINES

Several types of drill-sharpening machines are used in the United States, each consisting essentially of a frame on which two cylinders are mounted (one vertically, the other horizontally), each containing a reciprocating piston. Compressed air is employed as the motive power, the consumption ranging from 30 to 100 cubic feet per minute at 85 to 100 pounds pressure, according to figures given by the manufacturers. Some device is necessary to hold the drill steel firmly in place. The sharpening is accomplished by means of suitable dies or dollies, which are either attached to or struck by the proper piston and mold the hot steel into the desired shape. The piston and die acting vertically is used for drawing out the corners of a broken or a very dull bit, or swaging out the grooves between the points, or insuring that the bit is of the required gauge, while the horizontal one sharpens the cutting edges. With a suitable set of dies, the machine may be used also for the construction of new bits from ordinary drill steel.

The use of a sharpening machine results in some saving of labor cost. for but one operator is required, who need not even

be high-priced. Such a man can ordinarily turn out several times the work of a skilled blacksmith and helper sharpening bits by hand. One manufacturer claims that his machine, when handled by an expert, is capable of sharpening 250 drills per hour, but he states also that half that number, under normal conditions, is good work. With another type, the capacity is given as 60 to 100 sharpened drills per hour. The lowest of these figures is more than ample for the usual requirements of tunnel work since, according to figures obtained at tunnels visited, the number of drills ordinarily sharpened ranges from 100 to 200 per day, although in hard ground as many as 400 were used.

The labor saved in the blacksmith shop is only a minor consideration, however, for the real superiority of the machine over hand-sharpening lies in its ability to turn out perfect bits. Since the progress in tunnel-driving is often largely determined by the time required to drill a round of holes, this important part of the work deserves careful attention. It has been demonstrated repeatedly by practical experience that on comparing the cutting qualities of a machine bit with one sharpened by hand there is a marked difference in favor of the former. This is due to the fact that the bits come from the machine true to gauge, thus greatly reducing the danger of binding or sticking in the hole; there is, therefore, less delay in drilling and a smaller loss of time from this cause for the driller and helper (or perhaps the entire crew), and there is less likelihood of "lost" holes. Then, too, the bits being correctly shaped and properly sharpened, they not only "stand up" better and stay sharp longer, but they also drill faster, and it is not necessary for the drill crew to change steel so often, thus reducing another source of delay. The use of drill-sharpening machines at the ordinary tunnel plant is, therefore, strongly recommended not only for its saving of time and labor both in the blacksmith shop and in the heading, but also for its ability to make bits whose superior drilling qualities will easily pay, because of additional progress, a handsome return upon the money invested in the machine.

AIR METERS

Air meters are of various types, depending upon differences in principle and design. In one of them the volume of air is measured by causing it to impinge consecutively upon a number of turbine wheels mounted on a common shaft which is connected with a registering device by a properly designed master gear. The machine is calibrated to read in cubic feet per minute of free air and is claimed by the manufacturer to give accurate measurements of air under varying pressures. A second type operates upon the principle that, with a uniform difference of pressure on both sides of an orifice and a constant initial pressure and temperature, the quantity of air passed is proportional to the size of the orifice. In this machine the difference in pressure on the two sides of the diaphragm is kept uniform by the constant weight of a taper plug which closes the orifice until the difference in pressure is sufficient to raise the plug and support it. The taper is so designed that the amount of air passed through the orifice is directly proportional to the rise of the valve, and this movement is multiplied and transmitted to a needle which records it upon a moving sheet of paper, thus affording a means of measuring the volume of air passed. A third type consists in a device for determining the pressure due to the velocity of the flow of air in a pipe (which is proportional to the amount of air passed if the temperature and initial pressure are constant) and transmitting that pressure to one arm of a U-tube filled with mercury. The tube is balanced on knife-edges, and since the pressure causes a flow of mercury to the other arm, the balance is disturbed and the tube is deflected, the amount of deflection being commensurable with the flow of air. This is transmitted by levers to a recording needle. In a fourth type, although only a proportional volume ranging from 1/8 of 1 per cent. to 8 per cent. is actually measured, the recording device registers in terms of the full 100 per cent. volume.

Any of these meters may be used to determine the amount of compressed air delivered to a purchaser. Their most im-

portant use, as far as tunnel work is concerned, is in determining the amount of air used by rock drills. It is well known that all pneumatic rock drills show an increased air consumption (which is less in some than in others, to be sure, but appreciable in all) caused by leakage, etc., as the various parts become worn through use. This fact is quickly discovered in practice and a large number of actual tests bear out the statement that after six months' or a year's steady use of the ordinary rock drill, the amount of this loss will range from 20 to 40 per cent. This additional air is not only expensive to compress, but, what is of more importance, the efficiency of the drilling machine is lowered at the same time, and the man behind it is unable to do as much effective work, thus entailing further loss. If the drill repair man has to guess at the air consumption, it is very difficult for him, even though he is an expert mechanic, to send a drill from the repair shop back to the heading that will do as good work as when it was new. But if the shop is provided with some means of determining the air required by the drill, he is much better able to remedy the defects and make the proper repairs. This results in a saving of expensive power and increases the efficiency of the drill and the amount of work done by the driller. It is very desirable also to keep a record every time the drill leaves the repair shop, not only of the cost of repairs, but also of its present air consumption, in order that upon its next return a comparison may be made with the last record, as well as with the nominal air requirements. By such a course necessary repairs may be made, if the air consumption is excessive, that would perhaps have been unsuspected otherwise, while at the same time the manager may keep an accurate statement of drill repairs and inefficient drills may be weeded out. The following sample gives a rough outline of such a system:*

DRILL RECORD

Tool Piston drill	Maker..............	Size 2¼ inches
Purchased 2/1/10	Serial No. 123,456	Shop No. 12
Normal air consumption, 90 cu. ft. per min. at 75–80 lbs.		

* By courtesy of the Excelsior Drill and Mfg. Co.

Date	Air Consumption	Pressure	Repairs
2/24/10	94	76	2 side rods
3/10/10	99	78	2 pawl springs
....	...	..	1 leather cup
....	...	..	1 chuck bolt
....	...	..	1 chuck key
5/10/10	128*	75	1 air chest and valve*
back to	96	..	2 piston rings

* Excessive air consumption corrected by repairs indicated.

CHAPTER VIII

ROCK-DRILLING MACHINES

TYPES

As a rule, rock-drilling machines are classified primarily according to the motive power by which they are operated. The great majority of those used in tunnels are of the pneumatic type, but hydraulic and electric drills have been employed. For surface work, steam is sometimes substituted for compressed air by making a few minor alterations in pneumatic drills, and machines using gasoline power are also to be found on the market; but the difficulty with the former in disposing of exhaust steam and with the latter the products of combustion, prevent any extensive use of these types underground. The following paragraphs describe some of the principal features of the various rock drills employed in tunnel work.

Pneumatic Drills

The pneumatic rock drill consists essentially of a cylinder containing a piston or a hammer which is reciprocated by the proper admission, application, and release of compressed air. In the piston type of air drill, a drill steel provided with cutting edges is alternately made to strike and recede from the rock by the movement of the piston to which the steel is firmly attached. In the hammer drill, the steel does not reciprocate, but is held loosely against the rock to which it merely transmits blows received from a moving hammer. (See Figure 28.) Piston drills are, almost without exception, mounted in a shell or cradle which may be attached to some rigid support while the drill is in operation, but which is easily removed when necessary; a screw thread is provided also, permitting the drill to be fed forward in the shell as the hole grows deeper. In some types of hammer

drills, especially those used for stoping and trimming, the shell is omitted and the drill either is held in the hand or is provided with a telescoping feed, operated automatically by compressed air. In either type, some device is required to rotate the drill steel in order that the cutting edges of the bit may not strike repeatedly in exactly the same place. In cradle-mounted drills this is generally accomplished by a mechanism (consisting of rifle-bar, ratchet, and pawls) which is arranged to turn the piston or hammer, this in turn rotating the chuck holding the drill. Where the telescoping feed is employed it is necessary to rotate the entire machine by hand. Figure 29 shows a section through a piston pneumatic rock drill and gives a list of the principal parts.

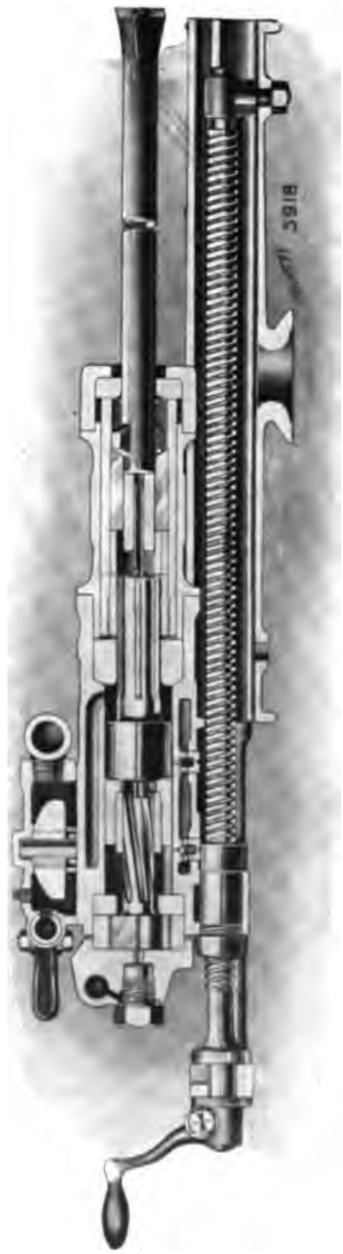

FIG. 28. Section through a hammer drill.

Pneumatic drills are often differentiated by the method employed in controlling the admission of air to the cylinders. This may be accomplished by tappet, air-thrown, or aux-

iliary valves, or the air supply may be regulated directly by the movement of the piston or hammer itself.

The action of the tappet valve is illustrated in Figure 30, which shows a section through a drill equipped with the same. As the piston in operation moves from the position shown in

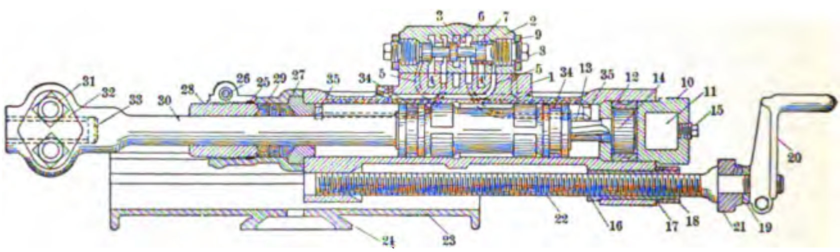

FIG. 29. Section through a piston rock drill.

1, Cylinder; 2, Air chest; 3, Inlet port; 4, Exhaust port; 5, Reverse ports; 6, Valve; 7, Valve bushing; 8, Buffer; 9, Check nut; 10, Top head; 11, Oil chamber; 12, Ratchet ring; 13, Rifle bar; 14, Ratchet; 15, Plug; 16, Feed nut; 17, Lock washer; 18, Check nut; 19, Washer; 20, Feed handle; 21, Yoke; 22, Feed screw; 23, Shell; 24, Trunnion; 25, Lower head; 26, Clamp bolt; 27, Bushing; 28, Gland; 29, Packing; 30, Piston; 31, Clamp bolt; 32, Chuck bushing; 33, Chuck button; 34, Piston rings; 35, Cylinder ports.

the cut toward the lower end of the cylinder, the crank end of the tappet rises, while the other end drops into the depression of the piston, thus producing a slight rotation around the tappet pin, which is sufficient to move the slide valve. This admits live air against the lower end of the piston, at the same time connecting the upper end of the cylinder with the exhaust pipe. The piston, therefore, starts in the other direction, and a similar, but reverse, process takes place.

The operation of the air-thrown valve is somewhat more complicated than the tappet, but by referring to Figure 29, which shows a section of a drill equipped with the usual form of air-thrown valve, the action is shown to be as follows: The piston is indicated as just starting on the down stroke, the valve being so placed that live air is entering the top cylinder port (35) from the air inlet port (3) by way of the connecting passages indicated by dotted lines, while at the same time the

front of the cylinder is connected with the exhaust (4) by the lower cylinder-port and its air-ways. The upper end of the "spool" of the valve is connected with the lower end of the cylinder—and hence with the exhaust—by the reverse port (5) (shown unshaded in the illustration). As soon as the piston in its travel uncovers the other reverse port (5) (shown by dotted lines), pressure from the upper end of the cylinder will be transmitted to the lower end of the spool and throw it against the upper end of the valve chest, and this will alternate the connection of the ports for live air and exhaust, thus reversing the piston. A similar process is then repeated on the upstroke.

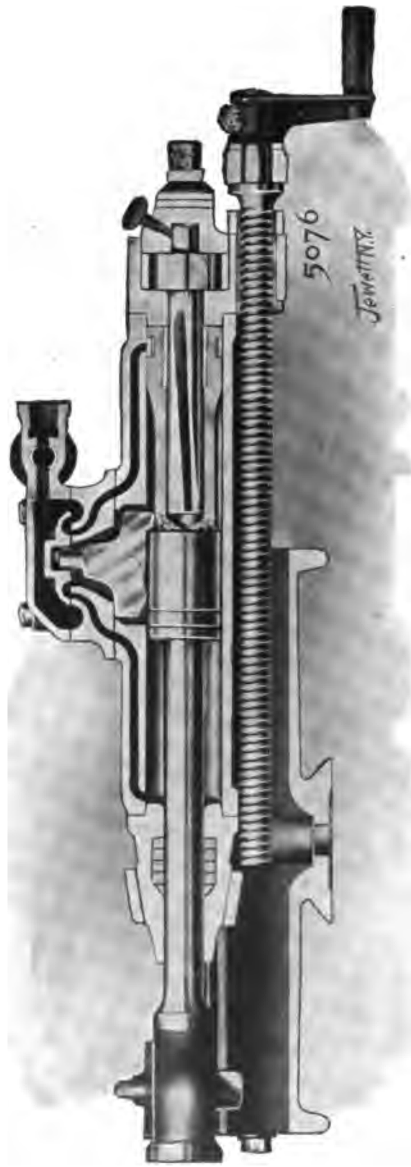

FIG. 30. Section of a tappet valve drill.

In a recent modification of the usual air-thrown valve the spool is replaced by a cylindrical shaft carrying two flat wings, which some-

what resemble those of a butterfly. The operation of this valve is illustrated somewhat diagrammatically in Figures 31, 32, and 33. In Figure 31 the piston *P* is represented as about

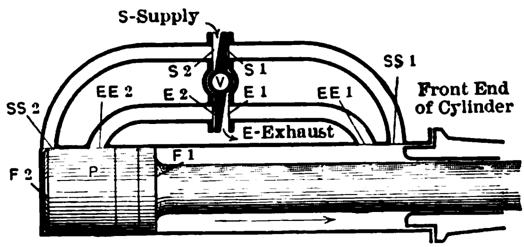

FIG. 31.

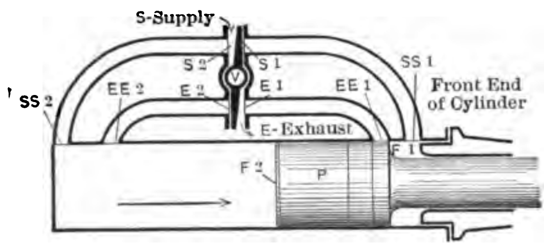

FIG. 32.

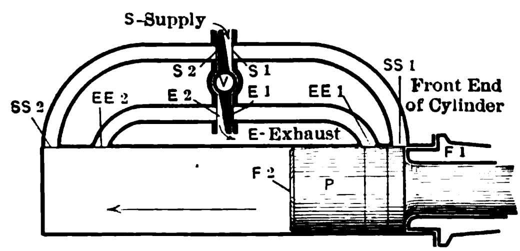

FIG. 33.

FIGS. 31, 32, and 33. Action of butterfly valve.

to start on the forward stroke. The valve is thrown so that live air is permitted to enter through the supply ports *S*, *S*2, and *SS*2, while the spent air in the front end of the cylinder is exhausting through the ports *EE*1, *E*1, and the exhaust *E*. As soon as the piston in its forward movement uncovers the exhaust port *EE*2, live air will pass through *EE*2 to *E*2, and its pressure on the valve at this point will balance its pressure on the opposite wing

of the valve facing port $S2$. The valve will then be in equilibrium, but will be held stationary with the ports $S2$ and $E1$ open because of the impact of the air opposite $S2$. Near the end of the stroke, however, the piston closes the exhaust port $EE1$, and in passing from $EE1$ to $F1$ it compresses the air which is trapped in the clearance space at the end of the cylinder. This cushion pressure, communicated through the cylinder ports $SS1$ to $S1$, is sufficient to throw the balanced valve to the position shown in Figure 33. Live air is then admitted, through $S1$ and $SS1$, the exhaust ports $EE2$ are opened, and the piston starts on the return stroke.

FIG. 34. Section through a tappet auxiliary valve drill.

One form of auxiliary valve used on a well-known piston drill is described as a mechanism in which

the strains, shocks, and jars to which the tappet or rocker is subjected are transferred from the main valve, with its vital and delicate functions, to a smaller auxiliary valve weighing only a few ounces, especially designed to withstand the service. This drill is illustrated in Figure 34.

When the drill is in operation, one end or other of the auxiliary valve projects slightly into the cylinder, and is thrown by the piston in its travel. The movement is perfectly free and very short—only enough to uncover a small port and release pressure from one end of the main valve, which is at once thrown by the resulting unbalanced pressure, opening wide the main port and admitting compressed air to the other end of the piston for

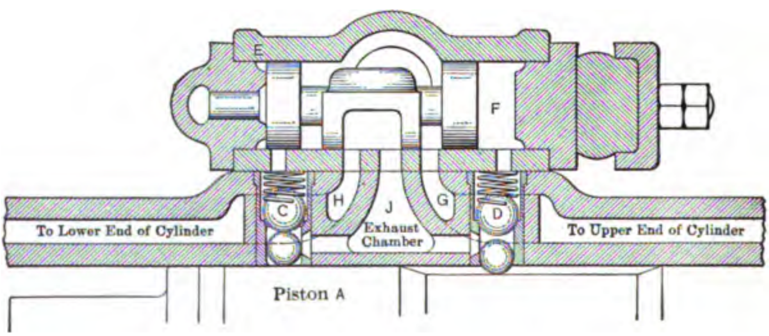

FIG. 35. Section through a steel-ball auxiliary valve.

the return stroke. The auxiliary valve is simply "a trigger which releases the main valve."

In another form of auxiliary valve, the main air-thrown spool is controlled by two auxiliary valves consisting of steel balls which are positively actuated by the movements of the piston. See Figure 35. In this figure the piston *A* is represented as having just started on the down stroke. Compressed air is entering the upper end of the cylinder through the port *G* and the spent air in the lower end is escaping through the port *H* and the exhaust chamber *J*. At the end of the stroke the ball *C* will drop on its seat and the ball *D* will be raised, thus allowing the air in the end of the valve chest at *F* to exhaust past *D* through the port between the upper and lower balls. The un-

balanced pressure thus produced throws the valve to the other end of the chest, which reverses the connections between the cylinder chambers and the inlet and exhaust ports. The piston therefore starts on the return stroke and a similar but reverse process takes place.

The valveless air-regulating mechanism, in which the movement of the piston itself covers and uncovers various ports, is employed almost exclusively on drills used for stoping only. Although rarely chosen for tunnel work, a brief description of this method of regulating air supply is warranted by its extensive

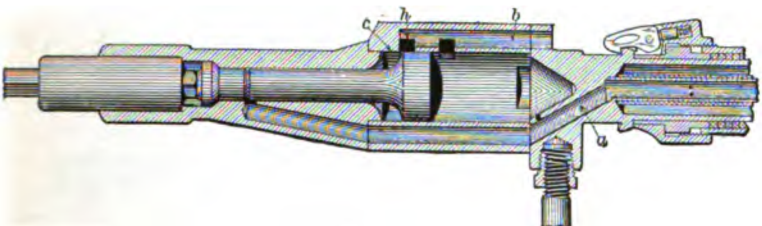

FIG. 36.

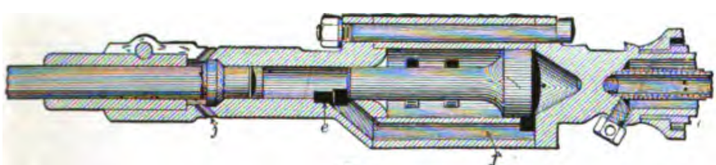

FIG. 37.

FIGS. 36 and 37. Cross-sections through valveless drill.

use in its own field. The principle of operation is illustrated in Figures 36 and 37, which are two cross-sections through the cylinder of one make of valveless drill. In Figure 36, air under pressure enters from the feed cylinder through the port *a* and passes to the front of the piston, where it exerts pressure at all times. The piston is forced back until the port *e* (Figure 37) is uncovered, when compressed air passes through the port *f* and exerts pressure on the top of the piston. Since the area of this face is greater than the striking end, the piston starts forward. Live air is shut off when the port *e* is closed, but the piston is pressed forward by the expansion of the air until the exhaust port *b* is opened just as the blow is struck on the drill steel.

Hydraulic Drills

The best known hydraulic rock drill is, perhaps, one of the rotary type developed for use in the Simplon tunnel, which consisted essentially of a hollow steel tube armed with teeth which were held firmly against the rock by hydraulic pressure while at the same time the tube was slowly revolved by a water-driven motor. Although, as far as could be ascertained, it has

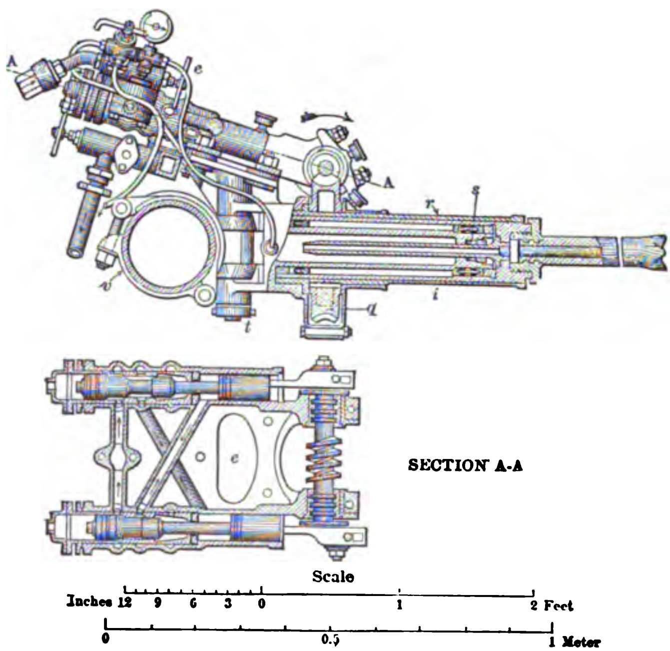

Fig. 38. Rotary hydraulic rock drill.

never been used for tunnel work in the United States, the introduction of the following description (see Figure 38), as given by Prelini,* we consider warranted by its historically interesting foreign achievements:

"This rotary motion is given by a twin-cylinder single-acting hydraulic motor (*e*), the two pistons, of $2\frac{7}{8}$ inches stroke, acting re-

* "Tunneling," page 103.

ciprocally as valves. The cranks are fixed at an angle of 90° to each other on the shaft, which carries a worm-gearing with a worm-wheel (q), mounted upon the shell (r) of the hollow ram (i), and this shell in turn engages the ram by a long feather, leaving it free to slide axially to or from the face of the rock. The average speed of the motor is 150 revolutions to 200 revolutions per minute, the maximum speed being 300 revolutions per minute. . . . The pressure on the drill is exerted by a cylinder and hollow ram (i), which revolves about the differential piston (s), which is fixed to the envelope holding the shell (r). This envelope is rigidly connected to the bedplate of the motor, and, by means of the vertical hinge and pin (t), is held by the clamp (V) embracing the rack-bar. When water is admitted to the space in front of the differential piston the ram carrying the drilling-tool is thrust forward, and when admitted to the annular space behind the piston, the ram recedes, withdrawing the tool from the blast-hole. The drill proper is a hollow tube of tough steel 2¾ inches in external diameter, armed with three or four sharp and hardened teeth, and makes from five to ten revolutions per minute, according to the nature of the rock. When the ram has reached the end of its stroke of 2 feet 2½ inches, the tool is quickly withdrawn from the hole and unscrewed from the ram; an extension rod is then screwed into the tool and into the ram, and the boring is continued, additional lengths being added as the tool grinds forward; each change of tool or rod takes about 15 seconds to 25 seconds to perform. The extension rods are forged steel tubes, fitted with four-threaded screws, and having the same external diameter as the drill. They are made in standard lengths of 2 feet 8 inches, 1 foot 10 inches, and 11¾ inches. The total weight of the drilling-machine is 264 pounds, and that of the rack-bar when full of water is 308 pounds. The exhaust water from the two motor cylinders escapes through a tube in the center of the ram and along the bore of the extension rods and drill, thereby scouring away the débris and keeping the drill cool; any superfluous water finds an exit through a hose below the motors, and thence away down the heading. The distributor, already mentioned, supplies each boring-machine and the rack-bar with hydraulic pressure from the mains, with which connection is effected by means of flexible or articulated pipe connections, allowing freedom in all directions. The area of the piston for advancing the tool is 15½ square inches, which under a pressure of 1,470 pounds per square inch gives a pressure of over 10 tons on the tool, while for withdrawing the tool 2½ tons is available."

A recently invented percussion hydraulic drill is described

fully in the *Engineer*,* from which Figures 39 and 40 and the following brief abstract are taken:

The drill consists essentially of a cylinder, in which is a piston *C*, free to move, while at the other end of the cylinder is a flap valve *D*, which is kept open by a spring. The interior of the cylinder is in

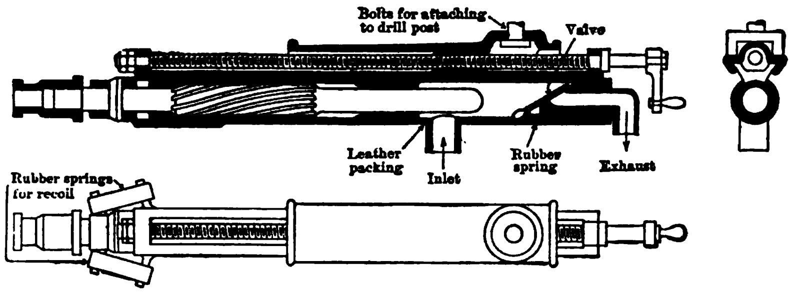

FIG. 39. Hydraulic percussion rock drill.

communication with a "striking tube" *F G*, at the end *F* of which is an air vessel. When the valve *H* is opened, water flows through the apparatus, out past the valve *D*, into the waste pipe *E*. The rush of water past the valves causes the pressure on the under side to be less than the pressure on the upper side, where the velocity is less. . . .

. . . When the velocity attains a certain value the difference of pressure is sufficient to close the valve, and the column of water in

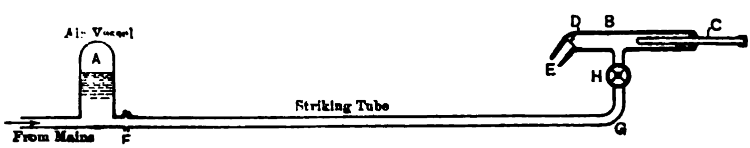

FIG. 40. Section through striking tube, hydraulic percussion rock drill.

the striking tube is suddenly stopped. The kinetic energy of the water in the tube is communicated to the piston *C*, which is impelled forward with high velocity, and the drill which is at the end of it strikes a heavy blow on the stone or rock being bored.

The pressure in the interior of the cylinder is diminished by the moving out of the piston *C*, . . . enough for the valve to open. Water then streams through the open valve. The piston is meanwhile being brought back to its original position by springs, but before

* "New Hydraulic Rock-boring Drill," the *Engineer* (London), January 7, 1910, page 24; 2½ cols. illustration.

it is right back . . . the valve *D* closes, and the direction of motion is reversed by the hydraulic shock. The drill then strikes another blow as before. The actual apparatus is shown in section and plan in Figure 39, which is roughly to scale, the overall length being about 4 feet.

The actual magnitude of the blow depends primarily upon (1) the weight of the striking column; (2) the velocity of the water when the valve closes; and (3) the weight of the chisel and boring bar.

The velocity of the column is fixed by the velocity at the valve required to produce the necessary difference of pressure to close the valve, *i.e.*, it is fixed by the stiffness of the spring controlling the valve. The rapidity of the blows is limited by the fact that after each blow the striking column is brought to rest, and it must be accelerated to the requisite velocity before the valve will close. The rapidity of working depends, therefore, upon the pressure which is urging the column forward, *i.e.*, it depends on the pressure in the supply mains. The actual magnitude of the blow is said to be unaffected by the varying pressure in the mains, and to depend only on the weight of the striking column and the strength of the spring controlling the valve. The inventor claims that machines of the type described strike from twenty to thirty blows per second, while the maximum speed of percussion machines of existing types is from three to five strokes per second.

One of these machines has recently undergone a series of tests at the Millbank Pumping Station of the London Hydraulic Power Company. The pressure used was 450 pounds per square inch. . . . The tests were carried out on a block of hard Portland stone. The diameter of the drill used was 2⅜ inches, and on an average progress was made in the stone at the rate of 10½ inches per minute. This is equivalent to the removal of 46 cubic inches of stone per minute. The drills stood up to the work so well that after holes aggregating about 25 feet in depth had been drilled, it was not necessary to do anything to the edge. A stream of water plays on the chisel the whole time, and serves the threefold purpose of keeping the chisel cool, of rinsing the bore-hole, and of allaying the dust.

Electric Drills

An electric rock drill consists primarily of an electric motor and a means of applying the power developed in it to the work of drilling rock. In some machines the motor is mounted directly upon the drill frame, but in others it is removed a short distance and connected to the drill by a flexible shaft, or some similar

device for transmitting power. Provision must also be made for preventing the shocks and jars developed by the impact of the drill steel upon the rock from being transmitted back to the motor, which is a machine incapable of operating for any length of time under such conditions. In many of the earlier models, springs or cushions of some elastic material such as rubber were used for this purpose. These devices failed to give satisfaction either because of inability to do the work required or because of excessive wear, breakage, and annoyance. In two or three of the early models, an ingenious attempt was made to avoid these troubles by taking advantage of the fact that if an electric current is passed through a spiral coil of wire, a suitably placed bar of soft iron will be drawn into it. By providing two such coils or solenoids and causing the current to flow through them alternately, an iron piston carrying a drill steel was made to reciprocate between them. In order to have the blow sufficiently smashing to be effective, however, a prohibitive weight of copper wire was needed for the solenoids. To-day practically all electric drills use compressed air in some manner to cushion the reaction of the blow,—a medium possessing the very desirable characteristic of extreme elasticity and at the same time not affected by wear and tear. In one machine, however, a hammer is made to strike the end of the drill steel by centrifugal force, the rebound giving the necessary flexibility.

One of the successful electrically driven rock drills that has been on the market for over five years is illustrated in Figure 41. In this machine the drill piston is reciprocated by alternating pulsations of compressed air, created by a double-cylinder air compressor driven by a standard electric motor. Two short lengths of hose connect the air compressor to the drill, each running from one of the compressor cylinders to opposite ends of the drill cylinder. The air in the system, which acts as an unwearing cushion between the pulsator and the drill, is never exhausted, but is simply used over and over. The drill is very simple—merely a cylinder containing a piston and rotating device—and valves, chest, side rods, buffers, and springs are omitted, while the compressor has neither valves nor water

jackets. The motor may be designed for either direct or alternating current as desired, and it is mounted with the compressor on a wheeled truck for easy handling.

A second air-cushioned electric drill of the piston type, but

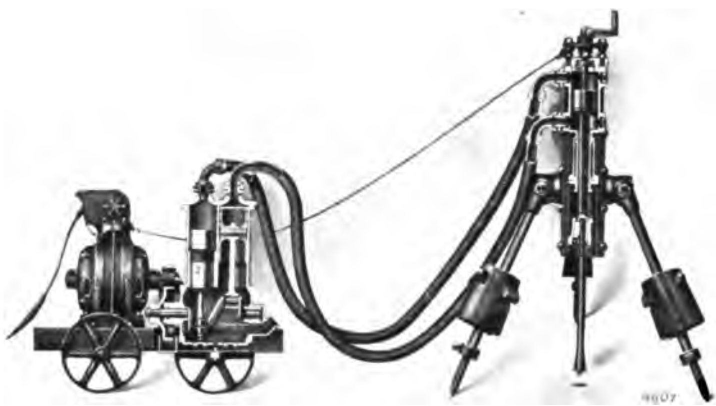

FIG. 41. Electrically driven rock drill, shown partly in section.

one in which the motor is mounted directly on the drill frame, is illustrated in Figure 42. In this drill the motor *M*, which can be readily detached from the rest of the machine whenever it is

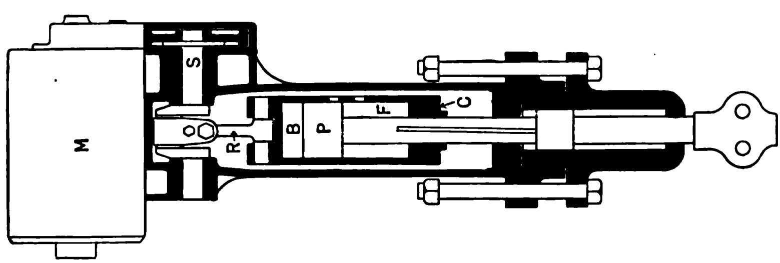

FIG. 42. Section through an air-cushioned piston electric drill.

necessary to move the drill to a new set-up, etc., is connected by reducing gears to a crank shaft *S*, which drives a connecting rod *R*. This is attached and gives a reciprocating motion to a cylinder *C*, which slides in suitable guides and contains a piston

P, provided with a chuck for holding a drill steel. As the cylinder moves forward, air is compressed in the chamber *B* behind the piston and makes the piston move forward, which causes the drill bit to strike the rock. During the return stroke of the cylinder, the compression of air in the other chamber *F* brings the piston back again with it. Rotation is secured by means of a standard spiral nut and ratchet. Details of the feed screw, the carriage, and other features are shown in the illustration.

In an electrically driven air-cushioned rock drill of the hammer type (Figure 43), power is transmitted by suitable gears and cranks from the motor to a piston and causes it to reciprocate in an air cylinder. The same cylinder contains at its other end a hammer, which, however, is in no manner directly connected with the piston. As the latter starts on the down stroke it compresses the air in the space between it and the hammer, which is projected forward until it strikes the end of the drill steel. Just as it does so it releases the compressed air by uncovering an exhaust port controlled by a poppet valve. When the piston starts on the return stroke the exhaust valve closes and a partial vacuum is created which pulls the hammer toward the piston. The latter in its travel uncovers an inlet port, also poppet controlled, admitting new air, which destroys the vacuum. The momentum of the hammer would cause it to strike the piston, which again starts on the down stroke were it not for the compression of this air entrapped by the closing of the poppet valve as soon as the vacuum is destroyed. The drill steel is rotated by the motor through a shaft, gearing, and a ratchet. Hollow steel is used through which water is forced to the cutting edge by a small pump supplied with the drill; but if water under pressure is already available, however, the pump may be disconnected. Another feature of this drill is the automatic chuck which is adapted for using steel as it comes in the bar, thus obviating the necessity of forging shanks.

A fourth electric drill, also having an air-cushioned hammer, is illustrated in Figure 44. In this drill as the yoke *A* moves forward, the piston *B* compresses the air in the chamber *C*, forcing the cylindrical hammer *D* against the anvil block *E*,

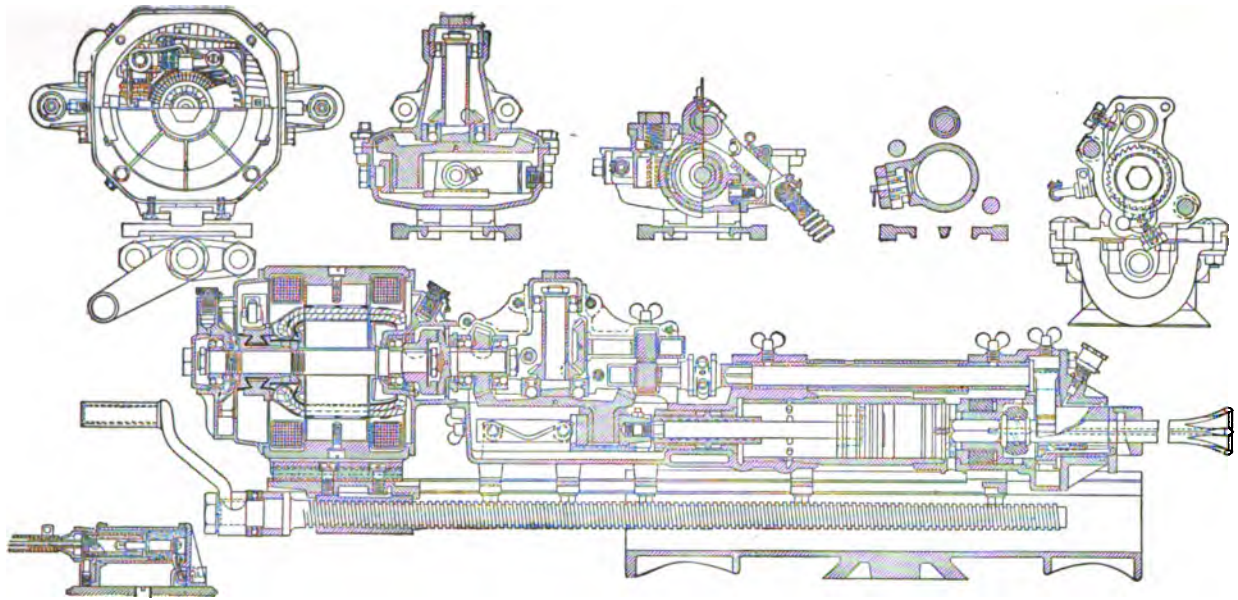

FIG. 43. Electric air-cushioned hammer drill.

which transmits the blow to the drill steel at *F*. On the return stroke of the piston, the compression of air in the chamber *G* brings the hammer back in readiness for another blow. Hollow

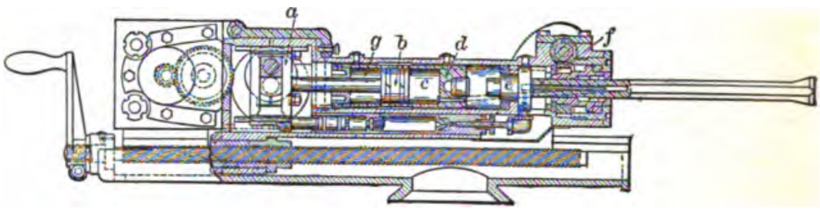

FIG. 44. Sectional view of an electrically operated air-cushioned hammer drill.

steel is employed through which water is forced by a small pump whose plunger reciprocates with the drill piston.

So far as could be learned, the only electric drill in service to-day which does not use an air cushion is the one illustrated

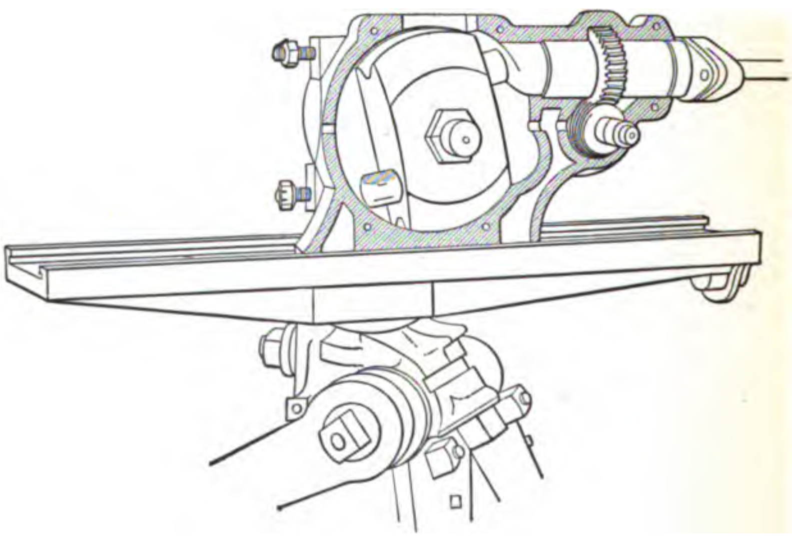

FIG. 45. Electric revolving hammer drill with motor and part of casing removed.

in Figure 45. In the illustration will be seen the two hammers which, although free to slide in their sockets in the revolving disk, are thrown out by centrifugal force and strike the anvil

block, which transmits the blows to the drill steel. The steel, which is held in a chuck rotated by a worm gear as indicated, is of the auger type, the spirals acting in the capacity of conveyor for removing broken rock from the hole.

Gasoline Drills

Since the difficulty of disposing of the waste products of combustion, which are not only hot and disagreeable but also contain gases injurious to the health of the workmen, makes the gasoline drill hardly suitable for service underground, and since as far as could be learned they have never been used in tunnel work, their design and construction will not be discussed here. A description of one of these machines having two explosion cylinders may be found, however, in the *Engineering and Mining Journal* for November 21, 1908, page 1,008; in the *Engineering News* for November 26, 1908, page 575, and in the *Mining and Scientific Press* for December 19, 1908, page 852. Another drill, one of English manufacture, in which a cam, driven by a gasoline engine, trips a spring-actuated piston, was described in the *Engineer* (London) for September 30, 1910, and in the *Engineering News* for November 17, 1910, page 538.

MERITS OF EACH TYPE

Pneumatic Drills

The chief advantage of the pneumatic rock drill is its ability to withstand rough usage and still perform efficient service. The work of a rock drill is done necessarily under conditions that would quickly destroy almost any other type of machinery. It is subjected to constant and severe vibration when in operation, for although it is usually held firmly and securely, still it cannot be mounted rigidly. Lubrieation, when supplied at all, is often administered in large doses most irregularly, and it is impossible to prevent sand and grit from getting into the machine, thus adding greatly to the wear and tear. In many cases, men who operate it have no conception of its construction, and ignorantly subject it to shocks and strains for which it was

never designed, their first impulse when things go wrong being to seize a sledge-hammer and hit the machine in the most convenient place. All drill runners, of course, do not belong to this type, but the description fits a much too large percentage of them. Everything considered, the rock drill must be capable of being operated under the most adverse conditions. This necessitates the elimination of all unsuccessful details, the rejection of complicated parts that are not absolutely essential, the determination of the proper size and strength of those remaining, and the selection of materials having the proper stability and wearing qualities. This can be accomplished in any machine only after patient development and experiment, and it is but natural that the pneumatic drill, which has been undergoing such a process for more than fifty years, should be able better to cope with these conditions and to operate more steadily with fewer interruptions and a lower cost for repairing broken or worn parts than any of the newer types.

Among other advantages of the pneumatic drill may be mentioned the facts that it furnishes a certain amount of ventilation, that it does away with the introduction underground of electricity at comparatively high voltages (which is oftentimes a source of danger), and that it does not require pipes strong enough to withstand the pressures needed for the rotary hydraulic drill. The air drill, however, should not be relied upon for ventilation, because, in the first place, the supply of air is intermittent, being arrested while the drill is stopped for the purpose of changing steel or moving it into position for a new hole, etc.; in the second place, the drills are not in operation immediately after the blast—the time when ventilation is most needed—although it is true that the use of pneumatic drills makes it possible to direct a jet of compressed air into the heading at this time to assist in removing the smoke; and, finally, there are on record cases in which the exhaust from the drills not only did not deliver fresh air but even filled the heading with carbon dioxide and other dangerous gases produced by combustion of oil and grease in the receiver, resulting, in one instance at least, fatally for several men. Again, at tunnels

using electric haulage the adoption of electric drills would simply add a little to a danger already present rather than introduce a new one, and in such cases the advantage of the air drill in this respect is not so important.

The most important disadvantage of the pneumatic drill, on the other hand, is its well-known lack of power economy. Since, as stated by E. A. Rix,* "the tables set forth in the trades catalogues for the consumption of standard piston rock drills are fairly accurate," let us determine from them the power required for rock drills by using his estimate of 20 b. h. p. per 100 cubic feet of free air per minute. The lowest figure given for any type of rock drill used at the tunnels examined for this report is 65 cubic feet per minute at 100 pounds pressure, while drills using as much as 150 and even 175 cubic feet were very numerous. On this basis, then, without making allowance for loss of power through friction in the pipes or leakage in the machines when they become worn, pneumatic drills require the application of from 13 to 35 brake horse-power at the compressor during the time the machine is operating. Although the rotary hydraulic drill employed in the Simplon tunnel required as much as 13 horse-power † (exactly the minimum figure just deduced for air drills) it is by comparing the power used in air drills with even the maximum of 6 horse-power for electric drills, many of which run on less than 2, however, that the large difference in power consumption is revealed.

Comparing the different types of pneumatic drills used in tunneling, the piston machine has somewhat the advantage over the hammer type as regards reliability and as regards efficiency in drilling holes vertically or nearly vertically downward. This reliability may be attributed without doubt to its simpler construction. It does not contain any mechanism for introducing a water spray through a hollow drill steel, it is not troubled by crystallization of metal parts from the repeated

* Address before the Mining Association, University of California, February 19, 1908.

† Comstock, Chas. W.: "Great Tunnels of the World." Proc. Colo. Sci. Society., Vol. VIII., p. 363.

shocks of rapid blows, and it has a much greater range of feed. This last item is a feature of importance when the machine is handled by an inexperienced operator, giving as it does greater latitude before the piston begins to strike the front head. These considerations make the piston drill more nearly fool-proof, and hence better adapted to use by ordinary drill runners—especially those in the Eastern States, who, as a rule, are neither as intelligent nor as careful as those in the West. Complexity of construction should not be confused, however, with the number of parts; for if this were taken as the standard, and every screw, bolt, or nut counted separately, it could be shown that the hammer drill is the simpler machine.

The greater efficiency in drilling holes which point downward was clearly brought out in the recent extensive drill competition in the Transvaal, according to the committee conducting the test, who reported that one of the main reasons for the better showing made by the piston drills underground was the fact that practically all of the holes drilled there were pointed downward. This is substantiated in several instances at tunnels in this country in which the excavation is accomplished by the heading and bench method; in such cases the piston drill is reported to have given better satisfaction in drilling the vertical holes required for the removal of the bench.

The principal advantages of the hammer drill, of the type used in tunneling, are a somewhat lower air consumption and a greater speed in drilling holes that are horizontal or nearly so, and especially those pointing slightly upward, such as are necessary under the ordinary methods in driving tunnel headings. In hammer drills the air consumption, and hence the amount of power required, varies from 65 to 100 cubic feet per minute at 100 pounds pressure (catalogue rating at sea level) as compared with 125 to 175 cubic feet for piston drills. The rate of drilling is of course largely dependent upon the character of rock penetrated, but by observation of the table below (in which it will be seen that piston drills, even in shale and sandstone, rarely drilled over 10 feet per hour, while the hammer drills in granite and other hard rock rarely fell below that figure, 15 and even 20 feet

DRILLING SPEED AS REPORTED AT VARIOUS TUNNELS*

Tunnel	Drill	Rock	Drilling Speeds per machine per hour (Feet)	Remarks
Carter	Hammer	Granite	10	"Approximately"
Catskill Aqueduct:				
Rondout	Piston	Shale	8	"A fair average"
Walkill	Piston	Shale	10½	"Normal conditions"
Central	Hammer	Gneiss	8–16	
Ft. Williams Water	Piston	Trap	2	"Phenomenally hard rock"
Gold Links	Piston	Gneiss	8–10	"Approximate"
Joker	Hammer	Breccia	12–15	
Laramie-Poudre	Hammer	Granite	15	"Ordinary conditions"
Los Angeles Aqueduct:				
Little Lake	Hammer	Hard granite	15.84	"Average of 15 accurately timed shifts"
Grape Vine	Hammer	Granite	10	"Estimated average"
Lucania	Hammer	Granite	13	"Average of 3 drills"
Marshall-Russell	Hammer	Granite	10–20	
Mission	Hammer	Shale and sandstone	30	"Medium ground"
Newhouse	Hammer	Gneiss	10	
Nisqually:				
Headworks End	Piston	Rhyolite	8–10	
Discharge End	Hammer	Rhyolite	10	"Rock is much harder than at other end"
Ophelia	Piston	Granite	8–10	
Rawley	Hammer	Andesite	15–20	"Average of 4 accurately timed drill shifts 19.7 feet"
Raymond	Hammer	Granite	8–12	
Siwatch	Hammer	Granite	10–15	
Snake Creek†	Piston	Diabase	8–12	
Stilwell	Piston	Andesite	5–10	
Strawberry	Piston	Shale	13	"Test run"
Utah Metals	Piston	Quartzite	6–8	

* Includes time used in setting up and tearing down column or bar and in shifting machine to new holes and in changing steel; but does not include time of mucking for set up or in loading, blasting, and clearing smoke.

† During a competitive test in which both drills were mounted on the same bar in order to secure identical conditions of rock, etc., the piston machine drilled 21 feet per hour, while a hammer drill made but 20 feet. The conditions were unusual, however, because water under pressure was encountered in practically every hole drilled, and doubtless influenced the results greatly.

being not uncommon) the general statement seems warranted that the hammer type has the greater speed in drilling the holes required in tunnel headings.

It is difficult to determine just how much of this greater speed is due to the manner of attack, the water feature, the greater ease and speed in replacing a dull steel with a sharp one, or to the non-reciprocating drill steel, but there is little doubt that all these factors enter into the result. The piston machine when attacking the rock strikes comparatively slow, heavy, smashing blows that soon dull the cutting edges of the bit, especially if the rock be hard, after which, until the steel is changed, the penetration must be accomplished by crushing. Conversely, the more frequent blows of the hammer type, being lighter, do not dull the bit so quickly and the penetration is effected by a chipping action which is speedier as well as more economical of power. The application of water through a hollow steel to the face of the drill hole, in addition to cooling the drill bit and preserving the temper of its cutting edges, affords a positive means of removing the cuttings promptly from the front of the bit. This not only prevents the recutting and grinding of material already broken, with a consequent saving of power, but increases the efficiency of the machine, since it enables the drill bit always to strike an uncushioned blow on "live" rock. Hammer drills having the water feature, however, are said to make a poor showing when drilling vertical holes. This is doubtless due to the fact that the velocity of the rising current of water in the drill hole is not sufficient to prevent the rock grains from settling against it to the bottom of the hole and interfering with the work of the drill. The plunger action of the piston drill, on the other hand, while it is probably no more efficient in actually removing the rock grains, keeps them stirred up enough partly to obviate the difficulty. Any one who has experienced the trouble and delay of changing steels with the usual chuck in piston drills will appreciate the saving in time and energy resulting from the use of a chuck into which the drill needs only to be inserted. Since in the hammer drill the steel does not reciprocate, the elimination of friction against the sides

of the drill hole effects a considerable saving of power and prevents a retardation of the blow, even though, as has been argued, it is partly offset by the loss of power in heating the hammer and drill end and in overcoming the inertia of the steel. An additional advantage of a non-reciprocating drill steel is the fact that it may be held against the rock at any desired point and a drill hole started wherever necessary without loss of time—a feature especially important where the face of rock is oblique to the drill.

The weights of hammer drills range from 115 to 170 pounds, while the piston machines used in tunneling at the time the field examination was being made for this volume weighed from 280 to 400 pounds, and the dimensions of the former were approximately four-fifths of the latter. This gave the hammer machines an appreciable advantage over the piston drills because they were lighter, smaller, and more easily handled in a restricted space. The shorter length of the hammer machine also made it possible to start the cut holes nearer the sides of the tunnel, thus securing a wider angle between each pair with a consequent increase in the chances of breaking the full length of the round of holes. Since that time, however, the leading manufacturers of drills in the United States have produced and are marketing piston drills that compare closely with the hammer machines in size, weight, and ease of handling, thus reducing these advantages in favor of the hammer drill.

Piston and hammer drills employed in tunneling are apparently on an equal footing to-day as regards cost of drill repair parts, although until quite recently the former had somewhat the advantage. From September, 1905, to March, 1906, hammer drills were employed at the Gunnison tunnel with a drill repair cost per machine of 13 cents per foot of hole drilled; but when piston drills were substituted the repairs were reduced to 3 cents per foot.* Two years later (September, 1907, to August, 1908), in driving the last 3,000 feet of the Yak tunnel, the cost

* In addition to the cost of materials, these figures include also a charge for the labor of the machinist making the repairs, which is not embraced in any of the values which follow. This fact must be considered in making comparisons.

of materials only for repairs to the hammer drills employed was but 1¾ cents, approximately, per foot of hole. At the Marshall-Russell tunnel, where hammer drills were employed, the average cost of drill repairs from June, 1908, to June, 1911, was but 1½ cents per foot drilled. Piston machines were used at the Strawberry tunnel from January, 1909, to September, 1911, the cost for repairs being nearly 2½ cents per foot drilled. On the Little Lake Division of the Los Angeles Aqueduct, where hammer drills were employed from July, 1909, to May, 1911, the average cost of drill repair materials as shown by the table was but 24 cents per foot of tunnel excavated. Since each of the two machines in the heading drills approximately 8 feet of hole for every foot of tunnel excavated, the cost per machine per foot of hole is 1½ cents.

COST OF REPAIRS FOR HAMMER AIR DRILLS. LITTLE LAKE DIVISION, LOS ANGELES AQUEDUCT. JULY, 1909, TO MAY, 1911

Tunnel	Tunnel Excavated, linear feet	Total Cost of Drill Repairs	Cost of Drill Repairs per foot of tunnel
1B South.......	1,030	$160.59	$0.156
2 North......	926	180.72	.195
2 South.......	419	64.75	.154
2A North......	460	46.28	.10
2A South.......	375	55.50	.148
3 North......	864	113.60	.131
3 South.......	2,149	505.01	.235
4 North......	448	67.03	.149
4 South.......	725	215.48	.297
7 North......	1,911	399.70	.209
7 South.......	1,024	493.46	.482
8 North......	225	146.56	.651
8 South.......	1,334	530.52	.398
9 North......	777	230.51	.297
9 South.......	2,479	404.94	.163
10 North......	2,626	585.78	.223
10 South.......	1,776	577.24	.325
10A North......	1,373	303.06	.221
10A South.......	1,756	359.27	.204

Average........$0.24

For 1910 and the first half of 1911 the repair cost of hammer drills at the Carter tunnel was 2 cents per foot of hole. At the Lucania tunnel, the repairs cost ½ cent per foot drilled,

but the hammer drills had been in use only one month. The hammer drills at the Rawley tunnel were new also, the repairs from May, 1911, to October, 1912, averaging 1.9 cents per foot of hole. These figures, which are based upon estimates furnished by managers or others in charge at the various tunnels, do not pretend to more than approximate accuracy; but they give a basis for comparison such as has been hitherto unattainable, although in making such comparisons the type of rock must of course be duly considered.

In spite of the development of other types of valve mechanism for air drills, the tappet valve, which was one of the pioneers in the field, possesses advantages which still keep it in demand for use on piston drills intended for certain kinds of work. Since it is unaffected by condensed moisture, which greatly interferes with the action of some other types, it is especially adapted for use with steam or with air containing a large amount of water vapor. Its distinctive advantage, however, is that its movement is positive; if the piston makes a stroke the valve must be thrown, hence there is no uncertainty in the action of the drill, no "fluttering."

The tappet drill is at a disadvantage when working in ground that will not permit of the use of a full stroke, because it is necessary for the piston to travel far enough to throw the valve, and hence too short a stroke is not possible. Then, too, as it is impossible to prevent some air being trapped in front of the piston and compressed after the valve is thrown, it strikes a cushioned blow. This is not always a disadvantage; in elastic and "springy" rock an uncushioned blow will not give the best cutting effect, while in sticky material compression assists the piston in starting on the return stroke. The tappet is subject to strains and wear which necessitate specially hardened material, not only in the tappet itself but in the bearing surfaces of the piston.

Under conditions that require a snappy, vicious blow with high air pressure, the ordinary air-thrown valve gives the best results. This feature makes it particularly applicable to hammer drills in which, because of the small size and weight of the ham-

mer, it is essential that there shall be no cushioning of the blow, and it is customarily employed on such of these machines as are not of the valveless type. When used with piston drills, the air-thrown valve permits a variable stroke; it renders possible at will a change in length of piston travel and force of blow. The short stroke and light blow possible with this type of drill make it easy to start a hole or to drill through seamy rock. After the hole is under way, or if the rock is solid, a full stroke is used to get the best efficiency from the machine. The air-thrown type of valve is not positive in its action, however, and is apt to be somewhat sluggish with air or steam containing much water. It is claimed for the butterfly type that it avoids this difficulty, as well as most of the troubles caused by freezing, and that it has a positive and at the same time a flexible action which permits of much higher speed than other valves.

The auxiliary valve is designed to combine the advantages of the tappet and the air-thrown valves while avoiding their defects. The lightness of the tappet auxiliary is said to prevent the injury or retardation of the piston and also to obviate the rapid wear of rings, piston, and cylinders caused by crowding against the opposite cylinder wall due to an unbalanced tappet not readily moved. A drill equipped with this type of valve has a wide variation of stroke and delivers an uncushioned blow. The main advantage of the steel ball auxiliary valve is the great resistance to wear and the cheapness of replacing the wearing parts. It is claimed for this valve that it assures a positive action of the drill without sticking or fluttering, and yet possesses the necessary flexibility.

The valveless method of regulating admission and exhaust has the advantage of simplicity and lighter weight due to the elimination of the valve and valve chest. It also uses air expansively, and this should result in economy of power. It strikes a cushioned blow, however, thus reducing the drilling power where the rock is hard and tough; but for medium rocks and especially with high air pressure the difference is said to be less pronounced because the lighter and more rapid blows chip rather than pulverize the rock and enable the drill to penetrate

readily. One real disadvantage is the fact that as the cylinder becomes worn there is a leakage of air past the piston, thus increasing the air consumption and interfering with the accurate working of the drill.

Hydraulic Drills

Among the advantages of the rotary hydraulic drill used at the Simplon tunnel should be mentioned the fact that the power was delivered to the cutting edge without the shocks, jars, and strains due to percussion, thus eliminating one source of wear and tear. The machine also utilized a very high percentage of the power stored in the motive fluid, its efficiency being given by one authority as 70 per cent. Again, by passing a portion of the waste water down the boring tube, chips and débris were promptly removed from the cutting edge, thus insuring the maximum boring power. On the other hand, the pressure required for operating this drill was enormous, ranging from 450 to 1,200 pounds per square inch according to one writer, and 1,470 pounds according to another. In any case the piping necessary to transmit the water under such high pressures must have been most expensive to install and maintain. The drill also required extremely heavy and rigid mountings to withstand the back pressure; these made it cumbersome and hard to move so that it could not be easily placed for a new hole.

The percussion type of hydraulic rock drill cannot as yet be said to have been demonstrated to be a practical success. It is an interesting possibility, however; because, like the hydraulic ram, it utilizes the shock that occurs in pipes at every stoppage of a moving column of water.

Electric Drills

Among the advantages claimed for the pulsator type of electric drill are saving of power, rapid drilling speed, simpler construction, and less trouble with fitchered drills. The motors which are used to operate the pulsator require, according to the size of drill, from 3 to 5 horse-power—a very small amount when

compared with the necessities of the ordinary pneumatic drill. Although it is true that the cost of power used by a drill is not the only item which determines its efficiency, such a marked difference in power consumption must necessarily exert a great influence. This fact holds especially in the case in hand, since it is claimed and apparently well substantiated by actual results that this machine is fully up to the drilling speed of any corresponding standard air rock drill and has practically the same cost for wages and fixed charges. The pulsator type also eliminates many parts, such as valves, springs, side rods, etc., which are sources of trouble and unreliability in other rock drills. It is able, moreover, to strike a very heavy blow because the pressure of air back of the piston is greatest just at the time of impact; and should the drill steel become caught in the hole from any cause the machine does not cease running, as is the case with air drills, but the pulsator continues to exert several hundred alternate pulls and pushes on the drill steel per minute; these in most instances are sufficient to loosen the drill at once, consequently saving considerable time and trouble.

On the other hand, the combined drill and pulsator are cumbersome and occupy a large space, every inch of which is precious in the tunnel heading—a disadvantage that increases directly with the number of drills needed for the work. For tunnel work it is necessary either to place the truck and pulsator upon the muck pile—a feat consuming extra time and energy and a position where it is subject to damage and breakage if the muck is being removed simultaneously with the drilling—or one must wait until the tunnel is cleared of débris before starting to drill, a procedure which is prohibitive if speed in driving is required. But under circumstances where there is no particular haste or in mining work where drilling and mucking are alternated, this disadvantage is not so serious.

The piston electric drill described on page 143 does away with the need of a pulsator, truck, and connecting hose, thus making a compact machine and one more comparable with an air drill. It is, however, quite heavy (weighing 490 pounds with the motor attached and 350 pounds without it, and is somewhat

difficult to handle and move in a small heading. It has a marked advantage over air drills in power economy, operating as it does on 4 horse-power, and actual results show that its drilling speed is fully up to that of standard piston pneumatic drills. At the Elmsford tunnel of the Catskill Aqueduct these drills are reported to have attained a speed of 100 feet in six to eight hours when drilling in a comparatively soft mica schist, but in the harder Fordham gneiss of the city tunnel the rate was but 60 feet per shift (eight hours). This drill is still in the process of development, in which it is necessary to correct the small defects that always appear in any newly designed machine when put to actual use, but the results attained with it in one portion of the city tunnel, Catskill Aqueduct, were very encouraging. One of the machines is reported to have operated there for more than five weeks, drilling over 4,000 feet of holes with none but minor repairs, such as pawl springs, etc.

The weight of the air-cushioned hammer drill and motor described on page 144 is about 150 pounds less than that of an electric piston drill and motor. With the motor removed, although it weighs more than a pneumatic hammer drill, it is but little heavier than a piston air drill of corresponding capacity. Its power consumption is rated at 2¼ horse-power and in the tests on the Catskill Aqueduct 6 to 8 feet per hour was the average drilling speed attained in ordinary work, including delays. This speed will undoubtedly be increased as the delays from breakdowns become less frequent. The drill was still being tried out and in the process of being perfected at the time of examination, so no data could be obtained as to its reliability.

The other air-cushioned hammer drill (see page 144) has been employed in several mines in Colorado, where, according to the testimonials, it is performing creditable service.

The average power consumption of the rotary hammer drill (see page 146) is about 1 kilowatt per hour (1⅓ horse-power). They were employed on the Elmsford contract of the Catskill Aqueduct and were reported as particularly efficient in comparatively soft rock, drilling at times as high as 100 feet per machine in an eight-hour shift.

CHOICE OF DRILL

The factors to be considered in the selection of a rock drill for tunnel work are, on the one hand, the cost of power, of attendance, of maintenance and fixed charges, and, on the other, the rate of drilling, the best drill being the one which combines all these factors in such a way as to develop the greatest drilling speed for the least cost. The power cost should include not only the actual power at the tunnel plant (with its charge for labor, fuel, interest, and depreciation), but all losses in generation, in transmission, and utilization in the drill. The wages of the drill-runners and all helpers required are just as much an item of operating cost as the charge for power. The cost for maintenance includes the cost of repair parts for the drill and the charge for the time of the machinist, together with the cost of sharpening drill steel. The fixed charges should include interest and depreciation on the cost of the drills and a proportion of the administrative expenses. The rate of drilling, on the other hand, should not be based upon the speed of penetration while the drill is actually hitting the rock, but should include all delays caused by the drill, such as loss of time in preparing the set-up, in shifting position to new holes, in changing drill steels, and any other interruptions properly chargeable against the machine.

Applying these specifications to the various rock-drilling machines, the hammer pneumatic drill is apparently the one best adapted for use under ordinary conditions in driving mine adits and tunnels. To be sure, its power consumption is more than that for electric drills, but it is about equal to the hydraulic and is less than the piston air drill. In the matter of attendance it has somewhat the advantage. Most of the piston air and the electric types usually require at least two men to operate each drill—a drill-runner and a helper—and the hydraulic machine requires five men.* With the hammer drill a runner is necessary, of course, but one helper often is able to attend to two drills

* Prelini, "Tunneling," p. 105.

or two helpers to three machines. We have just seen that there is practically no difference between the piston and hammer air drills as to repair cost. The multiplicity of parts in the rotary hydraulic machine, however, is said to have been a source of much trouble in this respect. Theoretically the hammer drills do not dull the steel so rapidly, and hence should have an advantage in this respect. Practically this is not an important difference because under ordinary conditions the blacksmith is rarely overtaxed, and hence the extra labor of sharpening a few bits more or less is not noticeable on the cost report. The fixed charges are such a small portion of the total cost of drilling that any discrepancy in them is rarely, if ever, large enough actually to decide the question. The rate of drilling is really the greatest factor in favor of the hammer type ordinarily used in tunnels. Not only does it penetrate faster when actually drilling, but, since its reciprocating parts are lighter and its vibration less than that of a piston machine, it can be employed with a lighter set-up, with a saving of time. Then, too, its ability to start a hole at any desired point and to drill rapidly holes that point upward enables it to be used advantageously on a horizontal bar with a saving of the one-half to one and one-half hours which are required to remove the débris before setting up the vertical column used almost without exception in tunnel headings for piston air drills. The hammer drill saves not only time in changing drill steels but energy as well, as any one who has wrestled with the ordinary piston chuck can testify.

For large tunnels excavated by the heading and bench method and in which a large number of holes are drilled downward, or perhaps at other places where, because of acidity in the mine water or some other reason, the water feature of the hammer drill would be unsatisfactory, or for other work than tunneling, the piston pneumatic drill would doubtless give equally if not more satisfactory results. Or if speed is not especially required and the drilling and mucking shifts can be alternated, the pulsator electric drill with its large power economy might prove the most efficient. And again, if the self-contained

electric drills continue to be improved as they have been recently, their greater economy of power will without doubt soon outweigh their lower drilling speed and present higher maintenance charges, especially at such places where electricity is readily available. On this account their development should be closely watched.

CHAPTER IX

HAULAGE

TUNNEL CARS

Most students of tunneling methods concede that an essential, and possibly the chief, feature of the problem is the rapid removal of débris produced in blasting; but it is commonly not so well recognized that the speed with which this may be accomplished is greatly influenced by the size of the tunnel-car. Large cars, even when empty, are heavy and cumbersome, but when full of rock they can be handled only with the greatest difficulty. To remove such a car from the heading and replace it with an empty one requires either several extra men to assist in the work or a horse or mule must be provided for the purpose. In the first instance men must be called upon who might otherwise be making arrangements for the rapid loading of the next car or doing any of the many things that make for speed and economy; while in the second, omitting altogether from consideration the cost and maintenance of the mule, delays and loss of time cannot be prevented. In addition to being unwieldy, large cars occupy a greater proportion of the actual space in the heading, constricted enough at best, thus preventing the shovelers from working to the best advantage; the added height involves a waste of energy because each shovelful of rock must be lifted a greater distance, making it impossible for the men to handle sufficient material in a given time. With large cars it is necessary to maintain a switch or siding near the end of the tunnel in order to permit the empty cars to pass the loaded ones, and time and labor must be expended frequently in relocating the switch nearer the heading to keep pace with the tunnel advance. The smaller car, on the other hand, when empty can be tipped off to one side out of the way and replaced easily when needed, thus giving a clear track for a loaded car and obviating the

necessity for a switch. In case of derailment, an occurrence by no means rare in practice because of the poor condition of most tunnel tracks, the large car, even when empty, is harder to replace, and when full it is sometimes necessary to unload all the material in order to get the car back on the track. It is true that a larger number of the smaller cars, each of which occasions some delay in its arrival and departure, are necessary to remove

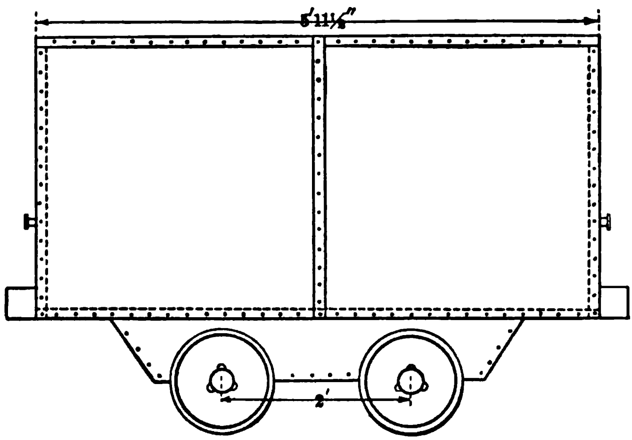

FIG. 46. Elevation of tunnel car used in the east end of the Gunnison tunnel.

the same amount of débris, but the authors are of the opinion, based upon a study of actual conditions at a large number of tunnels, that with proper organization greater progress is attainable by using smaller cars, the size preferred being from 15 to 25 cubic feet capacity. The tendency at many American tunnels is toward the use of cars much larger than this, especially where electric haulage is employed; but the use of large cars, when analyzed, has been shown to be a handicap rather than an advantage even in those tunnels equipped with them where creditable progress has been made.

In design, the cars at a majority of the tunnels visited follow the standard mining types with tilting bodies, but at a few of them other types were employed to meet special conditions. A car with a side-dumping, tilting-box body was used in

the west end of the Gunnison tunnel. End-dumping cars are similar to this except that the hinge is transverse instead of longitudinal and the door is situated at the end instead of the side. The car used at the Laramie-Poudre tunnel, which is illustrated in Figures 48, 49, and 50, was of the turn-table type, which permitted dumping from both sides of the track as well as between the rails. As the system of car handling in the headings at this tunnel necessitated throwing all of the cars over on their sides once (and nine-tenths of them twice) on each trip, the connections between the trucks and bodies of the cars were carefully planned and made unusually strong. The turn-tables were fitted with two concentric rings (Figures 49 and 50), and the locking mechanism for securing the bodies to the trucks was so designed

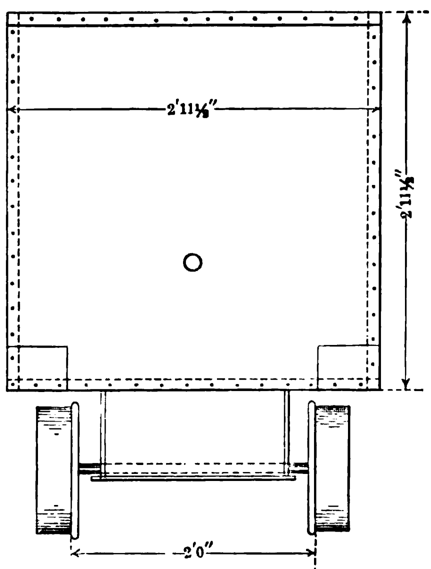

FIG. 47. End view of tunnel car.

that when the releasing lever was fastened in place the cars were as rigid as if the bodies were riveted to the axles. A car of the rocker type (see Figure 51) was used with very satisfactory results in the tunnels of the Los Angeles Aqueduct. At the Nisqually tunnel a similar car, but one with a slightly different locking

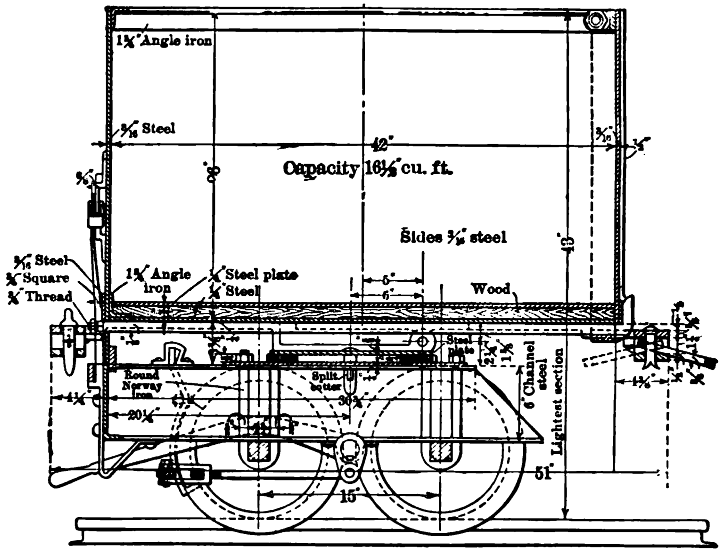

FIG. 48. Elevation of tunnel car used in Laramie-Poudre tunnel.

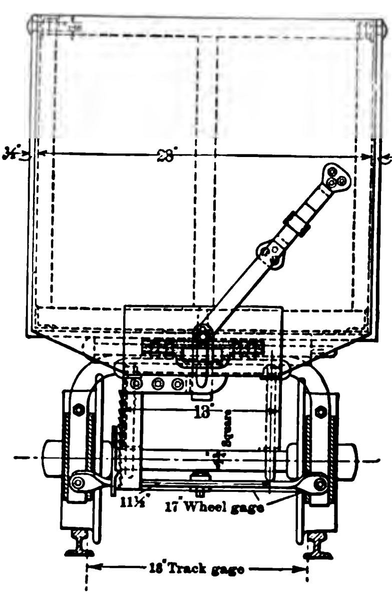

FIG. 49. End view of tunnel car.

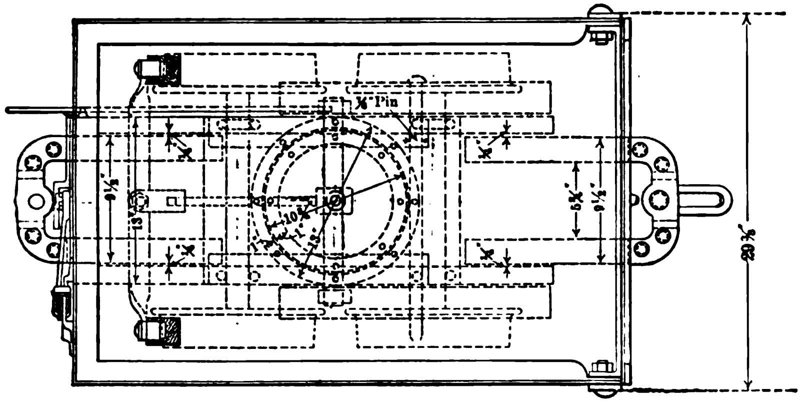

FIG. 50. Plan of tunnel car.

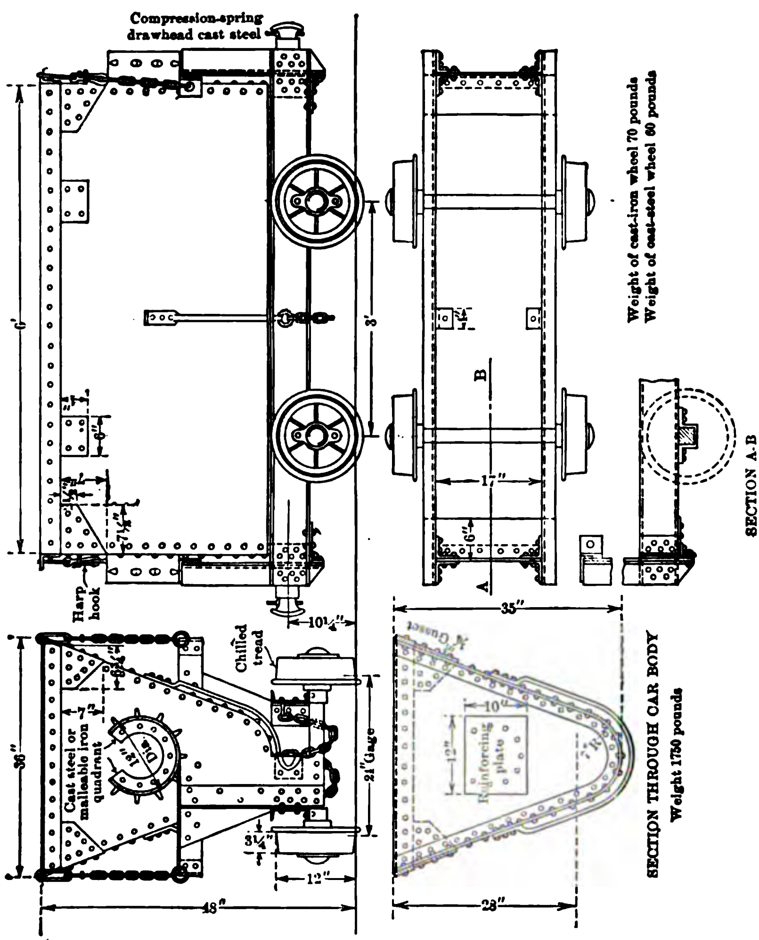

FIG. 51. Rocker dump tunnel car used on Los Angeles Aqueduct.

device, was employed. (See Figures 52 and 53.) In order to obviate the tilting body, the car at the Utah Metals tunnel was constructed with the floor permanently inclined toward the side

FIG. 52. Tunnel car used at Nisqually tunnel.

FIG. 53. Method of dumping tunnel car.

door, while at the Carter tunnel a car of the gable type was used, in which the floor slopes away from the center toward doors on each side of the body. At the east end of the Gunnison tunnel

DATA CONCERNING TUNNEL CARS

Tunnel	Type of car	Cp'cty, cubic feet	Gage Track, inches	Weight of Rail, pounds	Means of Haulage	Remarks
Buffalo Water	Rocker-dump	27	24	25	Electric	Trolley and storage battery
Carter	Gable-dump	21	18	12	Horse	
Catskill Aqueduct:						
Rondout	Side-dump	40	30	25	Mules	
Wallkill	Side-dump	40	30	25	Electric	
Moodna	End-dump	40	36	30	Mules	Automatic cage dump
Central	Turn-table, end-dump	30	24	20	Electric	Storage battery
Chipeta	....	20	18	..	Mules	
Cornelius Gap	....	81	36	..	Electric	
Fort Williams	....	18	18	12	Animals	
Gold Links	Turn-table, end-dump	..	24	20	Horse	
Grand Central Sewer	Bucket and flat car	14	24	..	Hand	
Gunnison, west	Side-dump	35	24	16		
Gunnison, east	Box	54	24	16	Electric	Derrick dump
Laramie-Poudre	Turn-table, end-dump	16	18	16	Mules	
Lausanne	End-dump	80	42	30	Electric	Cradle dump
Los Angeles Aqueduct:						
Little Lake	Rocker-dump	32	24	16	Mules and electric	
Grape Vine	Rocker-dump	32	24	16	Electric	
Elizabeth Lake	Rocker-dump	32	24	35	Electric	
Lucania	Turn-table, end-dump	22½	18	20	Horse	
Marshall-Russell	Turn-table, end-dump	28	24	16	Horse	
Mission	Side-dump	22½	18	25	Electric	
Newhouse	Box	..	..	..	Electric	Revolving dump
Nisqually	Rocker-dump	27	24	16	Electric	
Rawley	Turn-table, end-dump	17	18	16	Mules	
Raymond	Turn-table, end-dump	32	18	16	Horse	
Roosevelt	Turn-table, end-dump	16	18	20	Animals	
Siwatch	Side-dump	33	22	30	Electric	
Snake Creek	End-dump	20	18	20	Horse	
Stilwell	Side-dump	22	24	30	Horse	
Strawberry	Box	47	24	25	Electric	Derrick dump
Utah Metals	Side-dump	32	24	34	Electric	Sloping floor
Yak	Side-dump	33	19	30	Electric	

(see Figures 46 and 47, pages 164 and 165) a simple open box car with the body bolted directly to the truck was employed, and similar cars are now in use in the Strawberry and Newhouse tunnels. Although this car is ideal from the viewpoint of simplicity, it requires special equipment for dumping because the entire car must be turned completely over. The table on page 169 contains suggestive data concerning the cars used in tunnels and adits in the United States.

LOADING MACHINES

Many attempts have been made to utilize machinery for loading tunnel cars. In several of the larger tunnels intended for railway purposes, power shovels similar to those used in grading or in open-cut mining have been very successfully used in

FIG. 54. "Mucking machine" at the Hummingbird tunnel, Burke, Idaho.

removing the broken rock of the bench after blasting. In such cases the ordinary steam shovel is generally employed, making a few minor alterations so that it can be operated by compressed

air. Power shovels operated by compressed air are also employed in some of the mines in the Joplin, Missouri, district.

The "mucking machine" illustrated in Figure 54 was used successfully during the excavation of the Hummingbird tunnel, at Burke, Idaho. Its principal feature is an oscillating trough or shovel armed with teeth and driven by a compressed-air piston in such a manner that the forward stroke is appreciably faster than the return. When in operation the teeth rest upon a steel plate under the muck pile, and as the shovel is fed forward the broken rock is forced by the jerky motion backward along the trough and discharged upon a belt conveyer which delivers it to an ordinary mine car at the rear. The entire machine is mounted upon a wheeled truck or framework and is fed forward by a second compressed-air piston connected with a cross-bar which can be jacked against the sides of the tunnel. It is essential that the area of this piston be smaller than the one which drives the shovel; for then, if the latter encounters a boulder or other obstruction too solid for it to dislodge, the entire machine can move forward and back with the stroke of the larger piston. By this means the machine is not only prevented from injury before the obstruction can be removed, but in many cases it will work the boulder aside without any assistance. One man is required to operate the machine, and two more are needed to tram the car to and from the end of the conveyer and to shovel the rock out of the corners of the tunnel into the trough, for the machine does not swing from side to side, but merely cuts a swath down the center of the tunnel, and hence leaves a certain amount of material piled on each side of it. The machine is reported to have reduced the time required to clean the tunnel from 6 to 2½ hours and to have made it possible to increase the speed of driving quite materially.

The shoveling machine illustrated in Figure 55 is very ingenious and closely simulates the actions of a man shoveling. At the front is a scoop or shovel, armed with teeth, which is pushed under the broken rock and raised by the action of a chain-driven crank, so that the material is dumped into a hopper just back of the shovel. The hopper in turn travels a short

distance, tilts up, and dumps the rock on a belt conveyer which delivers it to cars at the rear. The machine was employed advantageously during the excavation of a portion of the Catskill Aqueduct directly under New York City. In this work six men were employed with the machine; one to operate it, three

No 15 Machine
Type No 3

FIG. 55. Shoveling machine.

to pick down the muck pile in front, and two to handle cars in the rear, as compared with the usual crew of fourteen men when mucking by hand. The power consumption was 25 to 30 kilowatts per shift. The machine would pick up a rock that ordinarily would take three men to put over the side of a car 30 inches high and a car holding 35 cubic feet could be loaded in 2½ minutes.

A power loader of a somewhat different type was introduced in the excavation of the bench at the Yonkers Siphon. It consisted of a chain-and-bucket conveyer, similar to that used in mill elevators and on some gold dredges, which delivered the material to a hopper, whence it was carried to the tunnel car by a flat endless belt.

Owing to the hardness of the rock and the prevalence of huge boulders, weighing sometimes over a ton and necessitating frequent stops for repairs, this machine was unable to compete satisfactorily with hand loading underground. When operating on the surface, however, loading rock for use in concrete construction it is said to have given excellent satisfaction. The

material was taken from the dump pile produced in excavating the heading of the tunnel in which the rock was broken more uniformly into smaller fragments than the material produced in blasting the bench. It should be mentioned, however, that the size of this machine precludes its use without considerable modification in a small tunnel or heading.

MOTIVE POWER

In practically all tunnels of any length in the United States, either animals or electric motors have been or are employed to haul the tunnel cars. In Europe, notably at the Simplon and Loetschburg tunnels, compressed-air locomotives were used successfully. But although those machines are employed to some extent in this country in mining and industrial work, they have failed to give satisfaction at tunnels where they have been tried, chiefly because of the cost of high-pressure air, the maintenance of charging stations, the time lost in charging, etc. Many mines also are equipped with cable haulage; but because of the constantly increasing length of haul as the heading advances, the use of this system in tunnel work requires such frequent delays and loss of time in extending the cable system that it is hardly suited for tunnel practice. Gasoline locomotives, on the other hand, which have recently proved most successful for coal mining, are in most particulars especially well adapted for tunnel work and deserve equal consideration with animals and electric motors as a means of tunnel haulage.

The principal advantage of animal haulage is the smaller cost of installation; what is more, it requires no special intelligence on the part of the driver, and the ability of the animals to step across the track at the tunnel headings obviates the necessity of a switch. On the other hand, the costs of maintenance and operation for animal haulage not only are high, but these factors go steadily on whether the animal is working or not and are influenced but slightly if at all by the amount of tonnage handled. For these reasons animals are not economical for use in long tunnels because the saving in installation expense is soon destroyed by the increased operating costs.

Then, too, the odors arising from the track are offensive and disagreeable when animals are employed and their respiration vitiates the underground atmosphere, necessitating more ample ventilation. As far as efficiency is concerned, there is little if any difference between horses and mules, although the latter are considered by some to be the sturdier animals. Mules, however, are better fitted for work in low tunnels because they are usually somewhat smaller than horses and, being less nervous, do not throw their heads violently up and back when anything touches their ears.

Electric mine locomotives may be divided into two classes: those operated from a trolley system and those obtaining their electrical current from a storage battery. The former are so familiar as hardly to require description. They generally consist of two motors, ruggedly constructed to withstand rough usage and protected from dust and moisture, mounted upon a cast-iron or structural steel frame which also carries the trolley, controller, rheostat, and other accessories. The sides of the frame may be placed either inside or outside of the wheels. In the latter type more space is available for the motors and other equipment and the various parts of the machine are more readily accessible. The inside type, on the other hand, has a smaller over-all width and is therefore more suitable for narrow tunnels. The storage battery locomotive is similar in most respects to the trolley machine, except that provision must be made for carrying the necessary batteries. In most cases the batteries are carried directly upon the motor itself, but the locomotive installed at the Central tunnel is somewhat unique in that the batteries are placed upon a separate battery car or tender. When the machine is handling cars in this tunnel it obtains its current from the battery; upon reaching the tunnel mouth, the tender is left on a side track, where it is accessible for recharging, and a trolley, with which the locomotive is also equipped, is employed for switching.

Electric locomotives are compact and simple in construction and do not emit smoke, gas, or disagreeable odors. They are more rapid and are capable of hauling a much greater load than

either a horse or a mule, while the cost of the power used is not nearly so great as the cost of forage. But, on the other hand, they require the installation of extra machinery in the power plant, an expensive trolley-wire or a troublesome storage battery, and the road-bed and track must not only be heavier in construction, but usually the rails must be bonded to make them good electrical conductors. The disadvantage of the cost of the extra electrical machinery is of course partly offset by the fact that it can be utilized also to operate the ventilating machinery and to furnish illumination for the tunnel. The use of trolley wires in the restricted tunnel space, however, introduces the grave danger of serious and perhaps fatal injury to persons accidentally or ignorantly coming in contact with them.

Gasoline locomotives consist essentially of a frame, as a rule of cast-iron, upon which are mounted the gasoline engine (usually

FIG. 56. Gasoline mine locomotive.

4-cylinder), the necessary transmission system containing gears and clutches, together with the carbureter, magneto, cooling system, and other accessories. In external appearance (see Figures 56 and 57) they are not unlike the electric locomotives

described above. Two forward and two reverse speeds are usually provided in the machines manufactured in this country, the lower one of 3, 4, or 5 miles per hour, and a higher speed double that of the lower. The draw-bar pull ranges from 1,000 to 4,000 pounds, according to the size of the locomotive. In

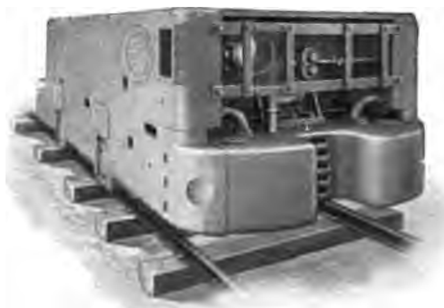

FIG. 57. Gasoline mine engine.

some of the machines the exhaust gases from the engine are passed through a tank containing a solution of calcium chloride, which cools the gases and is said to remove all offensive odors from them. In a German-made machine the exhaust gases are sprayed with water to produce the same effect.

The gasoline locomotive combines most of the advantages of both electric and animal haulage. It is self-contained and independent of a central station or any other outside source of power, needing nothing but a track. It is fully as rapid as the electric motor ordinarily used in tunnels and is capable of handling an equal load. The fuel for a gasoline locomotive can be obtained readily in almost any locality, and the machine does not consume fuel when it is not running, a matter of great importance in tunnel work, where interruptions occupy a necessarily large percentage of the time. Another advantage, although perhaps not so important for tunnel work, is the fact that the haulage system may be expanded by the addition of extra units without alteration in the power plant, hence the possibility of such future changes need not be considered in the design of the power plant. The following table, based upon replies from

OPERATING COST OF GASOLINE HAULAGE

	Breese-Trenton Mining Co., Trenton, Ill.	Durham Coal & Iron Co., Chattanooga, Tenn.	Henderson Coal Co., Pittsburgh, Pa.	Pocahontas Smokeless Coal Co., Welch, W. Va.	Roane Iron Co., Rockwood, Tenn.	H. B. Swope & Co., Madera, Pa.	Tennessee Consolidated Coal Co., Tracy City, Tenn.	Vaughen Coal & Coke Co., Roderfield, W. Va.	Alden Coal Co., Alden, Pa.	Midvalley Coal Co. Wilburton, Pa.	Munroe Coal Mining Co., Barnum, W. Va.	Shade Coal Mining Co., Mt. Pleasant, Pa.
Months in use	9	9	7	14	18	11	14	11	5	12	5	4½
Average number of trips each locomotive	30	12	12	15	9	20	35	10	20	7	20	12
Average gross tonnage loaded trip	30	20	40	35	36	32	19.5	27.5	50	60	21	61
Average gross tonnage empty trip	11	6	12	10	14	10	7	14	13.5	27	6	9
Average length of haul, one way, feet	2,200	1,000	5,200	2,400	5,800	3,000	2,500	10,500	1,750	11,500	3,000	2,000
Average number ton miles daily	515	59	615	307	600	475	440	830	1,270	1,320	300	740
Gallons fuel per day	20	15	8	12	13	15	15	16	9	15	20	15
Cost of fuel daily	$2.00	$1.65	$1.04	$1.44	$1.30	$2.25	$2.50	$3.60	$ .86	$1.50	$2.20	$2.20
Cost of labor per day	5.90	3.50	5.30	4.50	3.50	6.24	4.10	4.50	4.48	4.14	3.75	2.50
Cost of lubricating oil per day	.50	.85	.32	.35	.41	.25	.65	.90	.20	.12	.15	.86
Operating cost, exclusive of repairs	8.40	6.00	6.66	6.29	5.21	8.74	7.25	9.00	5.54	5.76	6.10	5.56
Cost per ton mile, not including repairs	.016	.101	.011	.02	.009	.018	.016	.011	.004	.004	.02	.0075
Average daily cost for repairs	not given	1.70	.33	.25	"not excessive"	.57	.50	not given	"none as yet"	.33	1.00	.22
Cost per ton mile, including repairs	....	.13	.012	.021	....	.020	.018	....	....	.005	.024	.008

operators and users of gasoline locomotives received in answer to inquiries sent out by the Bureau of Mines, in 1912, shows the cost of haulage with these machines.

Practically the only disadvantage of the gasoline locomotive is the amount of carbon-dioxide given off in the exhaust from the engine, but this can be eliminated by proper and adequate ventilation. When the machine is properly regulated the amount of carbon dioxide should not exceed 2½ to 5 cubic feet, depending on the size of the engine. If this were confined in a small unventilated space the air would soon become unfit for breathing, but since the greater part of the time the motor is traveling back and forth in the tunnel and since a large volume of air is, or at a properly organized tunnel should be, supplied by the ventilating blower, the exhaust gases from the engine are quickly diluted to harmlessness. It is essential, however, that the blower be arranged to deliver the air to the heading through the ventilating pipe rather than through the tunnel, in order that the air may reach the workmen as pure as possible, and it would doubtless be necessary to run the blower somewhat nearer its capacity. But even were it operated at full load, the added cost of doing so would be more than repaid by the saving effected by the gasoline haulage.

DUMPING DEVICES

The box cars used at the Strawberry tunnel were dumped by an electrically driven stiff-leg derrick. The hook in the derrick block carried a bail which engaged trunnions, one at each end of the car. The trunnions were placed in such a way that when an empty car was picked up by the bail the weight of the running gear would be sufficient to hold the car upright, but if the car was loaded its center of gravity would be above the trunnions. A spring-actuated pin, situated in one leg of the bail and engaging a hole in the car body above the trunnion, prevented the car from overturning until it was swung out over the place where the rock was to be deposited, when by pulling a rope the attendant could disengage the pin and permit the car to turn over and deposit its contents. It would then auto-

matically right itself and could be swung back on the track. The derrick was mounted on wheels so that it could more easily be moved ahead, but this was necessary only at intervals of three to six months.

Among the advantages claimed for this system of dumping is the fact that it could be operated by the train crew, the motorman running the hoist and the brakeman adjusting the bail, thus saving the labor of a dumping gang. Then, too, it gave a much larger dumping area with a consequent saving of the time which with the ordinary mine car is lost in shifting tracks, etc. But this was offset in part by the settling of the dump, and on this account the moving of the derrick was accomplished with great difficulty. It is probable that some of this annoyance could be avoided at a future installation by using very wide wheels similar to the type used on roller trucks for moving houses. But the derrick is expensive, costing when erected at the tunnel approximately $3,600, of which hardly more than $1,500 could be realized from its sale after the completion of the work; for this reason its use must extend over a considerable length of time in order that the saving in wages may repay the original cost.

At the Newhouse tunnel the loaded cars were run into a cylindrical steel framework having rails at the bottom and a set of angle-iron guides at the top with just enough clearance space between them to hold the car firmly. The entire apparatus was then revolved by an electric motor until overturned, emptying the contents of the car, and it was then righted by continued revolution and the car removed. Although used here only for ore cars, the material falling into a bin for shipment, it offers a satisfactory and reasonably inexpensive means of dumping the more durable solid body and truck cars, and could doubtless be applied to tunnel dumps by the use of a light trestle or similar structure.

Almost any of the various cradle dumps frequently used at coal mines can readily be adapted to tunnel work by mounting upon a stout frame of logs or large timbers, which could be pushed forward along the top of the rock pile as necessity arose. By this means it is possible to eliminate hinges and turn-tables

between the body and the truck of the car, thus simplifying and strengthening its construction. One of these cradle-dumps was used at the Lausanne tunnel. It was not expensive and saved a considerable amount of time in dumping cars and in keeping the rock pile in proper condition. It was pushed forward by the motor every two or three days, requiring but a few minutes for the operation. A similar dumping device is used at the Cameron mine, Walsenberg, Colorado. It has the added advantage of being mounted on a turn-table, thus giving nearly double the top width of dump attainable with ordinary cradle devices. As described in *Mines and Minerals*,* the dump consists essentially of three plates of one-eighth inch iron 3 by 4 feet in size. To the top plate are bolted a pair of mine rails with the ends bent up into horns. This upper plate revolves on a mine car axle, the bearings for which are supported upon a mine rail and bolted to the middle plate. A piece of channel iron is bolted to the middle plate and upon it the dumper falls back after a load of rock has been discharged. The upper plates as a unit revolve upon the two annular pieces of iron, 22 inches in diameter. The king-pin is 1 inch in diameter, and the plates, where it passes through them, are reinforced by a piece of ½- by 3-inch bar iron. The lower plate is supported by four short lengths of 12-pound mine rail.

* October, 1911, p. 158.

CHAPTER X

INCIDENTAL UNDERGROUND EQUIPMENT

TUNNELING MACHINES

Although tunnels have been constructed for mine drainage, irrigation, and supplying water to cities for thousands of years, they were so few in number during ancient times and constructed at such irregular intervals that there was no great incentive to improve upon the methods ordinarily employed in driving them. With the advent of the steam railroad, however, it was soon realized that the desirability of maintaining easy gradients would necessitate the driving of many tunnels, and the active minds of inventors were immediately directed toward the problem of making a machine which would do this work more or less automatically.

The first tunneling machine of which any record could be found was constructed at Boston in 1851 for use in the Hoosac tunnel. It weighed 70 tons and was designed to cut a circular groove in the face of the tunnel, 13 inches wide and 24 inches in depth, by means of revolving cutters. The trial of this machine in the tunnel proved unsuccessful, and only a distance of 10 feet was cut with it before it was abandoned. In 1853 the Talbot tunneling machine, which was designed to make an annular cut 17 feet in diameter and leave a cylindrical core to be removed by blasting, was tested near Harlem, New York, but also proved unsuccessful. Later a smaller machine was constructed, adapted to cut an 8-foot annular groove; this, while it was less unwieldy than its predecessor, also proved a complete failure after $25,000 had been expended upon it. Although numerous machines constructed upon almost every conceivable principle have been experimented with since 1853, the entire disappearance of most of them from sight, and almost from history, tells only too clearly that the problems of driving

through hard rock have been too difficult for the machines to overcome successfully.

It is not safe to predict from this, however, that a tunneling machine will not, or cannot, be constructed to perform this work in the future because, difficult as the problem of designing such a machine appears, the obstacles in the path are no greater than they have been in scores of other instances where slow and costly manual methods have been superseded by less expensive and more expeditious mechanical processes. The invention of some new rock-cutting device, or the material improvement of some of those now known, may simplify the problem to such an extent that the construction of a successful tunneling machine will be rendered comparatively easy. Further encouragement is also to be found in the fact that there have been two machines, designed for driving in the soft chalk formation underlying the English Channel, that have done practical effective work.

The first of these is generally known as the Beaumont machine, because, although invented by Major English, it was developed and operated by Major Beaumont, of the English Army. This machine, which was not completed until 1883 (although patented as early as 1864), during a series of tests drove an aggregate of more than 6,000 feet of cylindrical tunnel 6¾ feet in diameter. The maximum rate of progress attained was 81 feet per day, or 40 inches per hour. During the final test an average of 50½ feet per day was maintained for fifty-three consecutive days. The machine was afterward tested in the Mersey tunnel at Liverpool, where it made an average speed of 30 feet in twenty-four hours in soft red sandstone and a maximum of 40 feet per diem. As the Beaumont machine can be used only in soft rock, a description of its mechanism is hardly necessary here, but its record shows what can be accomplished in mechanical tunneling by a machine carefully designed for the work it is intended to perform.

The first patent on the Brunton tunneling machine was issued July 21, 1868; since then a number of patents have been granted for different improvements. While this machine, like the Beaumont, was designed primarily for driving in the chalk

formation under the English Channel, it was the direct outgrowth of the investigations and improvements on stone-cutting tools by the Brunton and Trier Engineering Company. The success of their stone-dressing machinery, now so largely used in this country and Europe, is due in a great measure to the perfection of the peculiar cutting tool which was employed in the tunneling machine, and which is described fully in an article on "Modern Stone-Working Machinery," by M. Powis Bale, in *Fielden's Magazine* for August, 1900, from which the following quotation is taken:

"The cutters are of steel and circular in shape, somewhat after the form of a saucer, and have a rolling motion when in action, consequently the great friction resulting from dead pressure is done away with, the cutters having what might be termed a rolling wedge action. This system of rolling cutters was patented some years ago by Messrs. Brunton and Trier, and the pith of the invention may be said to consist in giving the circular cutters a determinate motion on their own axis, at the same time they are carried around in a circle, their cutting edges describing a circular path and the rates of cutter rotation and movement around the circle being so adjusted relatively one to the other that the cutting edge rolls in a slowly advancing circular path."

The pressure of the sharp wheel against the rock causes the latter to spring off the side of the cut in the form of spawls, very much on the same principle as a sharp-edged wheel-tire will throw a line of chips when passing over a sheet of ice. As there is no percussion, the machine works steadily and quietly, even on the hardest rock, and the durability of the cutting disks is something phenomenal.

Good descriptions of the Brunton tunneling machine may be found in the following:

Drinker's "Tunneling," pages 191–194.

Zwick's "Neuere Tunnelbauten," page 68, with cuts.

Johnson, Wm.: "Brunton's Heading Machine," Proc. Chesterfield and Derbyshire Engineers, October 2, 1875.

Engineering, Vol. VII, page 355, May 28, 1869.

The machine was thoroughly tested out on both sides of the Channel, where it drilled an aggregate of approximately 8,000

feet, and it was found that a seven-foot machine would bore a tunnel and load the cuttings on dump cars at the rate of 30 inches per hour. Several thousand feet of tunnel were also driven with this machine in somewhat harder rock, but before it could be fully developed and placed upon the market further progress was stopped by the unfortunate death of the inventor.

Any future tunneling machine, to be successful in hard rock, will have to be simple, durable, not liable to derangement, easily guided and controlled, and with all parts readily accessible for removal, adjustment, and repairs. It must be so designed as to permit the automatic removal and loading of the cuttings and at the same time afford free access to the face even when it is in operation. All actuating machinery and bearings must be completely housed and protected from mud and water and the framework so constructed that it will not be thrown out of alignment or its advance checked by openings or softened places in the rock. It must also permit of easy removal to and from the immediate face of the tunnel. Viewed in the light of present development, this seems a difficult problem, but the invention of some new cutting device or material improvement in some of those now known may so simplify the task that the construction of a successful tunneling machine for hard rock will be rendered comparatively easy. This has been the course of invention in numberless instances, and we have every reason to expect that here, as elsewhere, history will repeat itself. The simple device of putting an eye in the point of a needle made the sewing machine possible; the breech-loading gun was a complete failure until the brass cartridge was invented; and not even the genius of a Langley or a Wright could construct a flying machine until the internal-combustion engine had reached its proper development.

At present, and during the last four or five years, inventors are and have been unusually active in this line of work, and there are several machines which are in the course of construction or are being experimented upon with the view of perfecting and correcting their mechanical details. The following are descriptions of some of the more prominent:

The tunneling machine which is being developed by Mr. O. O. App, of the Terry, Tench and Proctor Tunneling Machine Company, consists essentially of a rotating head with four arms, each of which carries four specially designed pneumatic hammer drills, so arranged that practically the entire face of the tunnel is covered at each revolution of the head. The drills carry a flat wedge-shaped bit and are arranged so that the action of the hammer is stopped automatically whenever the pressure of the bit against the rock is less than a predetermined amount, thus preventing damage to the drill whenever a tool breaks or a crack or seam in the rock is encountered. The drill bits are held against the rock at a definite angle, and in their operation they chip or flake away the rock instead of attempting to pulverize it. The head is provided with a flange and shield so arranged that the cuttings are lifted from the bottom of the bore and discharged upon a belt conveyer which in turn delivers them to the tunnel cars at the rear. Air is supplied to the drills through the center of the rotating shaft which carries the head. The entire machine is mounted upon wheels to facilitate its movement in the tunnel.

The Bennett tunneling machine consists of a battery of forty-six pneumatic hammer drills mounted in a rectangular head, arranged so that it can be given a vertical as well as a transverse motion, and thus be able to drill a tunnel of any desired size. The head is held rigid while the machines are running, and after the face of the tunnel has been drilled full of holes the head is backed away from the face and the cellular shell remaining between the holes is then broken down with hammers. Experiments are now being carried on with this type of machine in a rock heading near Golden, Colorado.

The International Tunneling Machine Company's machine is manufactured under the Fowler patents, and consists of a narrow swinging rectangular cutting head, the full size of the tunnel, carrying a battery of forty-one rock drills. These drills are so placed as slightly to overlap each other's path as the cutting head swings from side to side, by which means the entire face is cut away. This permits the continuous operation

of the machine, so long as it is in working order, instead of intermittent attack as is necessary with the Bennett type of machine.

A full-sized machine was built in 1909 at the Davis Iron Works in Denver, but, aside from some experimental cutting on a huge block of concrete, nothing was ever done with it, and it is now housed in the shop yard.

The Karns machine is in principle a large reciprocating rock drill with a cutting head the full size of the tunnel. In the latest machine this head is six feet in diameter and contains forty-one cutter blades made of tool steel, each 1 inch thick, 5 inches wide, and of various lengths. Points like saw teeth are machined on one edge and the other edge is fastened in the face of the head. The reciprocating parts of the machine weigh seven and a half tons and make about 140 strokes per minute of seven inches each. The head is rotated slightly on each return stroke. The machine uses 2,000 cubic feet of air per minute. One runner, one helper, two muckers, one engineer, and a fireman are needed to run the machine, and a blacksmith and helper are required, one shift in three.

The Retallack & Redfield tunneling machine, now under construction at the Vulcan Iron Works in Denver, is intended to bore an eight-foot cylindrical tunnel. A machine of this size carries twenty-eight percussion drills, symmetrically arranged on a revolving head, each drill having 3⅛-inch pistons, carrying 1¼-inch steel bits with the regular cruciform cutting face 6 inches in diameter, so shaped that the twenty-eight drills in one revolution cover and cut away the entire face. Behind the drills, immediately surrounding the cylinders which actuate them, is a steel tube about 6 feet in length and 7 feet 5 inches in diameter, or 7 inches less than the bore. The outside of this shell is surrounded by three-inch flanges arranged as a worm conveyer to force the cuttings back from the face. The rear end of this tube carries two small, pivoted, self-loading buckets or skips, which are filled at the lower part of their travel and emptied at the upper where they are inverted by a trip, discharging their contents on an endless rubber belt which carries the cuttings rearward and drops them into a car.

The Sigafoos tunneling machine is practically a horizontal stamp mill, the stamps being thrown forward by coiled springs and drawn back by a revolving cam. In practice ten heads are employed and the stamps, instead of being flat, carry an equipment of hardened steel faces designed to operate with as great a cutting effect as possible. To prevent the steel from heating and losing its temper, the entire face is sprayed with water, which not only lowers the temperature, but allays the dust and assists materially in removing the cuttings.

Although a number of experimental machines have been built, all of the details of construction are not yet perfected. The American Rotary Tunneling Machine Co. is now experimenting with an eight-foot machine near Georgetown, Colorado.

One of the great obstacles encountered by legitimate investigators in this field has been the difficulty of obtaining funds; for with the tunneling machine as well as with any other new and complicated machine built to operate under difficulties and strains which cannot be measured in advance, costly experimental work is necessary in its development and process of perfection. It must be remembered that machines of the size and strength to cut the entire face of the tunnel in a single operation are of necessity costly, and their maintenance during the trial stages is extremely expensive. For this reason, success can hardly be hoped for unless the inventor, or the company back of him, is in a position to command very considerable amounts of money. But the failure of one badly designed and inadequately financed machine after another, and the suspicions which have been aroused in the minds of possible investors by the untruthful and flamboyant "literature" which has been issued by too many alleged tunnel-machine companies in their efforts to "work the public," have caused most people to look upon machines of this kind with extreme distrust, much of which is indeed just, for even a casual scrutiny of the claims of many of these concerns shows clearly that they are in reality fit subjects for investigation by the postal authorities.

The following paragraphs contain a list of patents issued

in the United States for tunneling machines in hard rock, arranged in the order of seniority. With each patent is given a condensed description of the "objects of the invention" or the "patent claim." At the time the examination was made the Patent Office was rearranging this class of inventions, and therefore, although every effort was made to have the list complete, it is possible that one or two inventions may not have been included in it.

List of Tunneling Machine Patents

E. Talbot Stone-Boring Machine, U. S. Patent No. 9,774, patented June 7, 1853.

Description not available, but Patent Office drawings show a machine adapted to boring a cylindrical tunnel with rotating disk cutters. Two pairs of disks are used, carried on a revolving head supported by a large hollow horizontal shaft. This head is intended to be slowly revolved by a worm-driven spur gear, and through the hollow shaft is carried a jointed connecting rod by means of which the cutting disks are traversed across the face of the revolving head so that all portions of the heading are subject to the cutting action of the disks. The machine is quite crude in its design, and it is plainly apparent that it had not passed the experimental stage.

Charles Wilson, Springfield, Massachusetts, U. S. Patent No. 14,483, patented March 18, 1856.

Claims: Invention "consists in so arranging, constructing, and fitting the parts of a revolving cutter wheel that the cutters are gradually forced forward with a very slow motion, while the wheel carrying the rolling disks, or cutters, receives a compound motion, the one motion a revolution on its shaft, which is at right angles to the axis of the tunnel being bored, and the other motion a gradual rotation of said cutter-wheel and parts carrying the same on the line of axis or general direction of said tunnel. These two motions, in addition to the very slow forward feeding motion produced

by the rolling cutters, causes the gradual removal of the rock, or other substance, at the semi-spherical end of the tunnel."

CHARLES WILSON, Springfield, Massachusetts, U. S. Patent No. 17,650, patented June 23, 1857.

"The plan adopted in this method of tunneling is to bore a single ring and a central hole. By means of a charge of gunpowder, afterward placed in the central hole and exploded, the rock intervening between the central hole and circular groove is detached."

Claim: "Forming grooves in stone, or other mineral substances, by means of rolling disk cutters on axes set in alternate directions and arranging a series of rolling disk cutters revolving in such a manner as to cut a deep annular groove into the rock."

F. E. B. BEAUMONT, England (English Patent No. 1,904), patented July 30, 1864.

"Gang of cutters; supplementary valve; tappet and annular projection; hand feed; rotation automatic by worm and feather."

THALES LINDSLEY, Rock Island, Illinois, U. S. Patent No. 55,514, patented June 12, 1866.

Machine devised, "first, to cut circular concentric channels in vertical planes of rock and thus form circular concentric rings in the heading; second, to disrupt these concentric rings of rock and thus prepare them for removal; third, to detach the fragments of the disrupted rings and deliver them for transportation," etc.

EDWARD M. TROTH, New York, New York, U. S. Patent No. 66,422, patented July 2, 1867.

A reciprocating head carrying a number of drills arranged to vary the stroke. This head turns slowly, cutting a number of concentric grooves in the face. The rings of rock remaining behind are broken off by wedges.

RICHARD C. M. LOVELL, Covington, Kentucky, U. S. Patent No. 67,323, patented July 30, 1867.

This is a chipping machine, the chisels being operated alternately by their respective engines, the leading chisel

cutting half the depth and the following one completing the cut, and being reversed and changed in cutting back; the motor is operated by either steam or compressed air conducted to the engine by pipes from the exterior of the shaft or drift, etc.

JOHN D. BRUNTON, London, England, U. S. Patent No. 80,056, patented July 21, 1868.

Patent claim: "The use of an apparatus for excavating tunnels, galleries, or adits, wherein one or more cutting disks are caused to revolve on their axis, or axes, such axis, or axes, revolving around a center which also revolves around another fixed center."

EDWARD ALFRED COOPER, Westminster, England (English patent No. 1,612), patented June 20, 1871.

Claim: "The cutting of grooves, or chases, in stone or rock by the action of a series of chisels or jumpers, each worked by compressed air or steam acting in a separate cylinder and moved along its groove or chase, and all advance as the grooves or chases are deepened."

ALLEXEY W. VON SCHMIDT, San Francisco, California, U. S. Patent No. 127,125, patented May 21, 1872.

Claim: "In combination with a cylindrical drumhead arranged to rotate on its axis, a series of rotary diamond-pointed drills mounted on the periphery of the drumhead." By this means an annular groove the size of the tunnel is cut in the rock to a depth of about two feet, when the machine is backed out and the central core removed by blasting. These diamond-pointed drills are cooled by a stream of water sprayed into the annular groove.

FREDERICK BERNARD DOERING, Trefriw, North Wales, England, English Patent No. 4,160, September 27, 1881.

"A tunneling machine on which is mounted by means of brackets, or otherwise, a series of rock-boring machines or drills, say four, more or less, around a central boring machine or drill, each carried at the end of an arm, preferably consisting of a strong steel tube. This steel tube, which is accurately turned on its outer face, is supported

by one, two, or more accurately bored castings which are carried on a strong framework mounted on wheels. The boring machines or drills may be fitted with cross-heads carrying chisels, or they may have a single chisel attached with or without a cross-head. The drills strike and rotate a portion of the circle with each stroke in the usual manner."

THOMAS ENGLISH, Hawley, Kent, England, U. S. Patent No. 307,278, patented October 28, 1884.

"Invention relates to a machine for boring a circular tunnel by means of a boring head which consists of a strong boss having two arms projecting radially from it, each arm having a number of cutters fixed in front of it, each cutter being a bevel-edge disk fixed to the holder so that it can be turned partly around when one part becomes blunted. Jets of water from small nozzles play on the cutters to prevent them from heating."

HENRY S. CRAVEN, Irvington, New York, U. S. Patent No. 307,379, patented October 28, 1884.

This patent "relates to that class of machines which employ a drill or combination of drills constructed to cut or bore an annular groove the full size of the contemplated tunnel, leaving a cylindrical mass of rock at the end of the bore to be blasted out by a charge of explosives introduced in the central hole."

ROBERT DALZELL, Waddington, New York, U. S. Patent No. 332,592, patented December 15, 1885.

Claims: "In a rock-drilling machine the combination of a suitable frame carrying a rotating or oscillating tubular shaft having near its forward end a series of laterally radiating arms, having adjustably screwed to their outer ends one or more reciprocating or rotary drills with mechanism for operating the same both simultaneously or separately."

F. O. BROWN, New York, New York, U. S. Patent No. 340,759, patented April 27, 1886.

Patent claims: "A shell made in the shape and size of the required tunnel, provided with an air-tight cross partition having manholes closed by plates in the tube, a

central worm-boring mechanism, and a steam pipe passing through the airtight partition in the tube."

REGINALD STANLEY, Nuneaton, England, U. S. Patent No. 414,893, patented November 12, 1889.

Claim: "In a tunneling machine the combination of a frame carried on central tandem wheels working on the floor of the tunnel, a central threaded shaft carried by said frame and driving wheel working on said shaft, radial arms and horizontal arms on one end of said shaft and provided with cutters and scrapers depended for forming an annular groove around the face of the tunnel," etc.

Reginald Stanley afterward devised numerous improvements on this machine which were patented June 14, 1892; May 9, 1893; August 29, 1893; August 11, 1894; and February 16, 1897.

FREDERICK DUNSCHEDE, Essenberg, Germany, U. S. Patent No. 507,891, patented October 31, 1893.

"Invention consists of an apparatus by means of which an annular groove and a central blasting hole are bored into the rock so that, on inserting into said central hole an explosive and exploding the same therein, the rock or other material forming the core between the central blasting hole and the circumferential cut will be smashed and blown away."

JONAS L. MITCHELL, Chicago, Illinois, U. S. Patent No. 537,899, patented April 23, 1895.

Claim: "In a tunneling machine, the combination of a tunnel-forming cutter consisting of a tubular cutter head, a main frame having guides thèrein, and of a diameter adequate to enter the tunnel formed by the cutter, a carriage sliding in said guides and lying in the transverse planes of the bed," etc.

HARRY BYRNE, Chicago, Illinois, U. S. Patent No. 545,675, patented Spetember 3, 1895.

Patent claims: "In a rock-tunneling apparatus, the combination of an upright supporting frame, having a marginal frame corresponding with that of the tunnel and a

series of traveling percussion channeling machines arranged to travel on the outer surface of said frame; a flexible connection attaching the entire series of machines together and causing same to travel in unison, and means for operating said flexible connection."

ARCHIBLE BAILEY, Philipsburg, Pennsylvania, U. S. Patent No. 640,621, patented January 2, 1900.

Patent claims: "In a mining machine, the combination with a bed, the carriage, two reciprocating cutters, each forming a separate curve, and means for simultaneously reciprocating said cutters in opposite directions, whereby they balance the machine laterally, of a drill mounted on each side of the carriage and forming an aperture at the end of the kerf."

JOHN E. ENNIS, Chicago, Illinois, U. S. Patent No. 690,137, patented December 31, 1901.

Claims: "A tunneling machine having a digger mechanism, including a plow movable in a circular sweep, means for imparting said sweep movement to the plow, and simultaneously forcing forward in a spiral direction, and means for automatically shifting movements of the plow and causing it to travel from the perimeter of the machine inward, or from the axis of the machine outward, during its sweep movement."

PEDRO UNANUE, City of Mexico, Mexico, U. S. Patent No. 732,326, patented June 30, 1903.

Claims: "In a tunneling machine, the combination of a ram-head provided with a series of rammers having their rods inclined to the ram-head in and toward the direction of revolution of the ram-head, together with an inclination from the axis of revolution of the ram-head, and means for rotating and feeding said ram-head," etc.

JOHN PRUE KARNS, Cripple Creek, Colorado, U. S. Patent No. 744,763, patented November 24, 1903.

Claims: "The combination with a tunneling machine of a revoluble drill support comprising a plurality of ring and spoke members, each having grooved forward faces,

drills, or cutters, having their base portions adapted to said grooves, each of the drills or cutters having a rearwardly projecting stem extending through an opening in the support, and means for locking said stems to said support."

Other patents issued to Mr. Karns on this machine are as follows:

No. 957,687, May 10, 1910, for improvements in machine structure, particularly for the front bearing of the cutter-head shaft.

No. 977,955, December 6, 1910, for improvements in the cutter-head tool-carrying spider.

No. 1,023,654, April 16, 1912, improvements on the structural form and mechanical arrangement of said machine.

CHESTER T. DRAKE, Chicago, Illinois, U. S. Patent No. 747,869, patented December 22, 1903.

Claims: "In an excavating machine, the combination of a shaft provided on its end with a cutter, mechanism for revolving the shaft, mechanism for giving shaft and cutter an orbital revolution, and adjustable mechanism for varying orbit described."

ALVA D. LEE, of Brookline, and FRANCIS J. E. NELSON, Jr., of East Boston, Massachusetts, U. S. Patent No. 874,603, patented December 24, 1907.

Claim: "In a rock-drilling machine, the combination of an annular face plate provided with a plurality of depressions in its face, means for rotating said plate and a plurality of cutters secured in said depressions, with their axes radial to the axis of said plate and at different distances from said center, thereby effecting in the revolution of said plate a cutting from the central opening to the outer periphery of said plate," etc.

SILAS A. KNOWLES and WALTER E. CARR, Idaho Springs, Colorado, U. S. Patent No. 875,082, patented December 31, 1907.

Claim: "In a tunneling machine, a narrow rectangular reciprocating cutter head of the full height of the tunnel to be driven, provided with vertically and parallely ar-

ranged rows of chisel-shaped drill bits having angular bases, means for securing said drill bits to said cutter head, said cutter head having slideway slots therethrough, a supporting guide arm having forward terminal arms which project into slideway slots on which said cutter head is reciprocally mounted," etc.

WILLIAM J. HAMMOND, Jr., Pittsburgh, Pennsylvania, U. S. Patent No. 885,044, patented April 21, 1908.

Claim: "In a tunneling machine, a rotary head having a series of diametrically arranged reciprocating hammers and separated from each other by distances slightly less than the hammers, whereby the entire breast of the tunnel may be disintegrated by the rotation of the head and the reciprocation of the hammers."

GEORGE ALLEN FOWLER, Georgetown, Colorado, U. S. Patent No. 891,473, patented June 23, 1908.

"Invention is directed to the production of a pneumatic mining machine for a plurality of thrust-actuated drills adapted particularly to tunnel or driving operations in which the drills are carried by a pivoted block, which, in its cutting operations, is automatically caused to travel back and forth, reducing the wall of the breast to an arc of a circle to give clearance to the sides of the machine."

OLAN S. PROCTOR, Denver, Colorado, U. S. Patent No. 900,950, patented October 13, 1908. Assigned to the Terry, Tench & Proctor Tunneling Machine Company.

Claim: "In a rotary tunneling machine, the combination of a supporting frame, a tubular shaft revolubly mounted on said frame, a rotary cutter head secured to one end of said tubular shaft, a plurality of operative rock-drilling engines arranged to cut the breast area of a circular tunnel, said cutter head having ports leading from said tubular shaft to said rock-drilling engines, means, including a motor, for rotating said tubular shaft and cutter head, means for connecting the opposite end of said tubular shaft to a supply of suitable drilling engine actuating fluid, a muck-catching cylinder on said supporting frame sur-

rounding said cutter head, and means for conveying the muck from said cutter head and cylinder to the opposite end of said supporting frame from said cutter head."

RUSSELL B. SIGAFOOS, Denver, Colorado, U. S. Patent No. 901,392, patented October 20, 1908.

"The objects of this invention are: First, to provide a rotary tunnel machine adapted to automatically feed into the breast of a tunnel as fast as it cuts into rock, and to automatically feed forward and backward. Second, to equip it with a plurality of reciprocating cutter heads, each provided with a plurality of independent rock-cutting lips. Third, to provide a plurality of reciprocating rotary cutter heads adapted to strike spirally twisting blows. Fourth, to provide discharge jets of water throughout the circumference of the rock-cutting area. Fifth, to provide the machine with a plurality of independent rotating and spirally striking cutter heads arranged and adapted to permit any one or predetermined number of said cutter heads to be adjusted to strike blows at differential force. Sixth, to provide an automatic adjustable feeding mechanism that will feed the machine forward in any predetermined curved path as it cuts its way into the rock."

JOSEPH RETALLACK, Denver, Colorado, U.S. Patent No. 906,741, patented December 15, 1908.

This machine is especially designed for driving tunnels or drifts through rock, and it comprises, in general, "a revoluble tool head which may be idly rotated or fed forward or backward at pleasure. The head carries a large number of independently actuated rock drills which attack the face of the rock as the head is rotated. The head is carried by a threaded shaft that is hollow from end to end and serves as a duct for the passage of the air or other fluid to actuate the drills." Provision is also made for introducing water at the drilling point and for automatically gathering up and conveying away the fragments of rock as the tunneling operation proceeds.

CHARLES A. CASE, New York, New York, U. S. Patent No. 910,500, patented June 28, 1909.

"This invention relates to means for disintegrating rock and other materials by suddenly changing their temperature, and then by concussion, hammering, or rasping, effecting their disintegration."

EDWARD T. TERRY, New York, New York, U. S. Patent No. 917,974, patented April 13, 1909.

"The primary object of this machine is to cut a tunnel through rock without the necessity of blasting." . . . "The drill head consists of nine gangs of drills of such size and location that in their rotary motion they cover substantially the whole face of the tunnel, while the cutting action is produced by a rapid reciprocation of the separate heads."

LOUIS FRANKLIN SLEADE, Denver, Colorado, U. S. Patent No. 945,623, patented January 4, 1910.

Claim: "A tunneling machine comprising a revoluble cutter head, an electric motor for rotating said cutter head, an internal combustion engine for maintaining a reciprocating motion of the said cutter head in a forward direction, and means for connecting said electric motor with said internal combustion engine, imparting a returning movement to the cutter head."

GEORGE R. BENNETT, Denver, Colorado, U. S. Patent No. 958,952, patented May 24, 1910.

Claim: "A tunneling machine comprising, in combination with a suitable support, a battery of rock drills, means for presenting said battery to a working face, means for projecting said drills of said battery in said face, and means for automatically moving said battery laterally after each projection of said drills.

"A tunneling machine comprising, in combination with a suitable support, a battery of rock drills, means for imparting a series of rectilinear movements to said battery, and means for automatically performing said movements, in progressive cycles, each cycle comprising a longitudinal, lateral, and vertical movement."

William R. Collins, Georgetown, Colorado, U. S. Patent No. 973,107, patented October 18, 1910.

"Invention provides a machine having a cutting head which will leave an uncut rock core, thereby saving a certain amount of expensive rock drilling, and further to provide an improved arrangement of chipping or cutting drills whereby the recoil of the drills will be counteracted and the cutting head balanced."

On August 8, 1911, Mr. Collins obtained U. S. Patent No. 1,000,075 for certain mechanical improvements on this machine.

Aron G. Seberg and Edwin G. Seberg, Racine, Wisconsin, U. S. Patent No. 976,703, patented November 22, 1910.

Claim: "In a drilling machine, the combination with a wheel, of shields yieldingly mounted in said wheel, drills slidably mounted in said shields, means to force said drills beyond the outer ends of said shields, and means to rotate said wheel.

"In a drilling machine, the combination with a rotating sleeve, of a wheel for said sleeve adapted to rotate therewith, a supporting axle around which said wheel revolves, means to rotate said wheel, a plurality of drills carried by said wheel, and rotating means adapted to force said drills outwardly and enter the same into an object."

Franklin M. Iler, Denver, Colorado, U. S. Patent No. 986,293, patented March 7, 1911.

Claim: "In a rock-drilling machine, the combination with a suitable frame, of a hollow rotatable shaft, carried by said frame, divergent, rigid, hollow arm constituting a continuation of said hollow shaft and projecting therefrom at an angle, means for supporting fluid-operated drills by said arms in various adjusted positions at different points, and means for connecting the inlet ports of said drills with the interior of said arms."

Mr. Iler has also patented, for use with his machine, a special drill bit which consists of a hollow tube about 7 inches in length, 3½ inches external diameter, and 1½ inches

internal diameter. This tube is of cast iron or soft steel, and in it are embedded a number of rods about ½ inch in diameter of exceedingly hard alloy steel. The soft material wears away much more rapidly than the hard, thus forming a chipping tool which can be used without sharpening until it is worn out.

GEORGE A. FOWLER, Denver, Colorado, U. S. Patent No. 996,842, patented July 4, 1911.

Invention "provides a suitable frame mounted on wheels, said frame being provided at its forward end with a drill head provided with a plurality of fluid-operated drills, said head being pivotally mounted on the frame and adapted to swing from side to side in the arc of a circle, upon a vertical axis, means being provided for admitting fluid under pressure to said drills, and for automatically swinging said head from side to side and for manually moving said machine forward against the breast of the tunnel."

ROBERT TEMPLE, Denver, Colorado, U. S. Patent No. 1,001,903, patented August 29, 1911.

"Invention provides a machine for cutting tunnels through rock or other materials, the cutter of which will be reciprocating and simultaneously moved transversely to its direction of reciprocation, thereby cutting a tunnel of greater cross-section than the machine."

Claim: "In a rock-cutting apparatus, the combination with a transversely extending head, of a plurality of cutters mounted thereon, means for reciprocating said head, and means for simultaneously moving the same in complete cycles over a substantially circular path adjacent to the surface worked upon and eccentric to the said head."

JOHN NELS BACK, Seattle, Washington, U. S. Patent No. 1,011,712, patented December 12, 1911.

Claim: "A tunnel-excavating machine comprising an outer frame, traction wheels under said outer frame, an inner frame movable with relation to said outer frame, a head beam, a carrier slidably mounted upon said head beam, a shovel mounted in said carrier, means for sliding the

carrier, means for moving said inner frame, and toggle-joint braces to prevent movement of said outer frame."

EDWARD O'TOOLE, Gary, West Virginia, U. S. Patent No. 1,011,955, patented December 19, 1911.

Claim: "In an excavating machine, the combination of a frame, a pair of rotary pick-armed cutter heads mounted on parallel shafts therein, and geared to rotate in unison from a common source of power, said frame movable upon a bed-plate, and in movement causing the shafts of said cutter heads to move transversely in their common plane, said bed-plate provided with a passage for excavated material, and with an intake extending beneath the path of movement of said cutter heads."

HENRY F. SUTTON, Salt Lake City, Utah, U. S. Patent No. 1,025,029, patented April 30, 1912.

"Object of invention is to subject the rock alternately to the action of opposite extremes of temperature, it having been found that when rock is first heated and then suddenly chilled it becomes softened or partially disintegrated so as to be easily removed by hand or by pneumatic tools or the like."

Claim: "Apparatus for tunneling rock, including a hollow head having a mixing chamber therein, said head having a working face formed with a plurality of minute apertures, means for pivotally supporting the head close to the surface to be acted upon, means for directing fuel into the head, valves for controlling the passage of fuel through said means, and means for directing air under pressure into the head."

ADOLPH F. WALTHER, Oakland, California, U. S. Patent No. 1,026,335, patented May 14, 1912.

Claim: "A tunneling apparatus comprising a plurality of main frames, detachable braced supports for holding said frames in a tunnel, a frame movable longitudinally in said plurality of frames, a rotary shaft and head mounted in said frame, radial bars provided with cutters mounted

on said rotary head, and mechanism for operating said rotary head and cutter bars."

L. H. ROGERS, New York, New York, U. S. Patent No. 1,039,809, patented October 1, 1912.

Claim: "The combination of a central frame, a hollow shaft journaled in the frame, means to conduct a fluid to the interior of said shaft, a front head fastened to said shaft, grinding wheels journaled on said head, motors connected to the wheels carried on the head, means to conduct the fluid from said shaft to said motors, a rear frame slidably connected to the shaft, a cylinder encircling said shaft and fastened to the rear frame, a piston in the cylinder connected to said shaft, and means to lead a compressed fluid on either side of the piston."

W. F. WITTICH, Erie, Pennsylvania, U. S. Patent No. 1,043,185, patented November 5, 1912.

Invention utilizes "a rotating head in which is mounted a series of cutters actuated, preferably, independent of the head, so that the head may be advanced slowly or rapidly, depending on the material being operated upon, and the cutters given a speed which will assure the greatest efficiency. In the preferred form of the machine, also, the head is separated from the driving parts of the mechanisms, so that the machine may be utilized and rapidly advanced where there is considerable leakage through the walls. The invention also contemplates a suitable mounting, or frame, for carrying the working parts, taking away the muck, and driving the several parts."

ILLUMINATION

With few exceptions, illumination for tunnels and adits in the United States at the present time is furnished by electricity, acetylene gas, or candles. The smoky open-flame miner's oil-lamp is occasionally used in tunnels situated in the coal-mining districts, and, of course, under conditions which prohibit the use of an open flame, safety lamps must be employed. When acetylene gas is employed it is usually generated

in portable lamps, but during the work on the water conduit for Washington, D. C., in 1899, this gas was manufactured at a plant on the surface and carried by pipes underground where it was burned in jets at regular intervals. Coal gas was similarly employed at the Mt. Cenis tunnel, which was started in 1857 and opened for traffic in 1872. The following table, however, shows the present practice with regard to means of illumination.

MEANS OF ILLUMINATION AT VARIOUS TUNNELS

Tunnels	Illumination
Buffalo Water	Electric lamps.
Carter	Acetylene lamps and candles.
Catskill Aqueduct	Electric lamps at intervals and usually a cluster of lamps in the headings.
Central	Acetylene lamps.
Fort Williams	Electric lamps (16 c.p.) every 75 feet and one 32 c.p. in heading
Gold Links	Candles.
Gunnison	Electric lamps. Cluster in heading and candles.
Joker	Electric lamps.
Laramie-Poudre	Acetylene lamps for drillers, candles for muckers.
Lausanne	Miners' oil lamps and safety lamps.
Los Angeles Aqueduct	Electric lamps and candles.
Lucania	Acetylene lamps.
Marshall-Russell	Acetylene lamps.
Mission	Electric lamps every 200 feet, cluster in heading, candles.
Newhouse	Electric lamps at stations, acetylene lamps in heading.
Nisqually	Electric lamps every 75 feet, cluster in heading.
Ophelia	Candles.
Raymond	Electric lamps every 200 feet, cluster in heading.
Rawley	Acetylene lamps.
Roosevelt	Electric lamps.
Siwatch	Electric lamps every 200 feet and candles.
Snake Creek	Acetylene lamps.
Stilwell	Electric lamps in heading, candles.
Strawberry	Electric lamps every 135 feet, cluster in heading.
Utah Metals	Electric lamp at switch, acetylene lamps in heading.
Yak	Electric lamps.

Neither candles nor the open-flame oil lamp can be recommended as a means of lighting a tunnel or adit during construction. Practically everything that can be said in their favor is that they require a much smaller initial outlay than electricity

or acetylene, yet they are more expensive per unit of light than either acetylene or electricity, consume a greater amount of oxygen, and give off a correspondingly greater amount of noxious gases. Candles not only do not give enough light, but what they do supply is flickering and unsteady unless there are no drafts, and since they are quickly extinguished by the exhaust blasts from air drills they cannot be placed to light properly the work of the drillers; hence the efficiency of a high-priced drillman is greatly reduced. Candles are often wasted or dropped into the muck-pile, an item of loss which may amount to a considerable sum in the long run. The open-flame oil lamp cannot be prevented from giving off soot and smoke which obscure and dim the light thrown on the work, while the soot collecting in the miner's throat and lungs irritates the mucous membranes and renders them easily susceptible to disease.

Electric incandescent lamps possess a number of advantages for tunnel work. They give a brilliant and steady light—one that is not affected by drafts and neither pollutes the air with soot nor vitiates it by consuming the oxygen. By combining several of them in a cluster, plenty of light in the heading is obtained for the drillers and shovelers, tending toward efficiency. To offset this advantage, however, the fact remains that unless they are used in connection with electric locomotives, drills, or similar machinery, the cost of lamp installation is almost prohibitive; even with the electric appliances in use the extra wiring and the lamps themselves are expensive, while the latter are subject to considerable loss through breakage. Electric lights are also at a disadvantage because they are not easily portable and the removal and replacement of bulbs and wires in the heading before and after blasting complicate an already involved situation. Moreover, this means of illumination is uncertain, especially in wet tunnels, because the chance occurrence of a short circuit through moisture, accident, or carelessness throws the entire work in darkness, and if other means of lighting are not at hand, stops all work until the trouble can be remedied. Again, whereas the use of electricity under ground is always attended with some danger, this is especially

true in the case of lighting appliances; the supposition is that the wires are protected, but the rough usage to which they are subjected soon destroys insulation, rendering persons who handle them (as they must do frequently) subject to severe shock.

One is tempted to say that the ideal means of tunnel illumination is found in the portable acetylene lamp, combining as it does the advantages of other illuminants while avoiding most of their defects. It may be obtained on the market to-day in a number of different designs and sizes adapted for practically every kind of work; the one most generally observed at the tunnels visited was about the size of an ordinary can of fruit and capable of burning for from eight to ten hours on one charge of carbide and water. Although too large for use on a cap, it was provided with a hook so that it could be suspended from any convenient place. Lamps suitable for wearing on an ordinary miner's cap are obtainable and these lights will burn for two or three hours without recharging, an operation which can be done easily in two or three minutes. The initial expense of an acetylene lamp is not high and it furnishes the brightest known artificial light used for underground work, with the possible exception of the electric arc, consuming the while only one-fifth as much oxygen as candles. The lamps are ordinarily provided with a reflector, which not only concentrates the light upon the work where it is needed, but shields the flame from drafts so that it will burn steadily unless placed directly in front of the exhaust from an air drill. Extensive use in some of the larger mining companies in this country has shown that the cost of the carbide is much less than either oil or candles and the use of acetylene lamps practically cuts the cost of light in half. At the Saginaw mine, Menominee Range, Michigan, the cost is reported as only two cents per shift of ten hours. Such lamps require practically no attention, are completely portable, and are not subject to breakage as are incandescent lamps. By giving the workman plenty of light his efficiency is not only increased, but he is better able to see and guard against the dangers of underground work, such as an insecure

roof, an unexploded stick of dynamite in the muck-pile, or any other of the many dangers to which he is at all times exposed.

TELEPHONES

Although it has been repeatedly stated in newspapers, engineering periodicals, and even by State legislatures, that every mine should be provided with a telephone system, the importance of telephones in tunnel work cannot be too often reiterated, not alone because of the greater safety they insure, but on the ground of efficiency and economy as well. The sources of accident in tunnel work are too numerous to mention —falls of roof, caves, premature or delayed explosions, water, and noxious gases being some of the more common. When an accident occurs in a tunnel that is equipped with a telephone system, not only can assistance be summoned quickly, but provision can be made beforehand for the care of injured men when they reach the surface; if professional help can be summoned and due preparation made *while the men are still on the way from the heading*, invaluable time is saved; for there have been, and doubtless will be in the future, many such instances where prompt medical attention has decided the question of life or death. Then, too, failure to obtain a proper round of holes in the given time, difficulty in blasting them to the full depth, or any of the many problems that commonly arise in tunnel-driving, call for a decision on the part of the foreman as to the method of procedure. Ordinarily the man entrusted with this position is capable of meeting such conditions as they arise, but it stands to reason that the work of the shift will be more efficient if the foreman can be in touch constantly with the mine superintendent and when in doubt receive suggestions and advice from the more experienced man's better judgment. Delay can be avoided in good part if the tunnel is equipped with a telephone, because the necessity that involves sending for fresh materials, tools, powder, etc., can either be foreseen and provided for promptly from the outside without the loss of a man from the heading crew, or when unexpected emergencies arise, only half the usual time is necessary to obtain the needed

supplies. It does not require many suspensions of work by the men in the heading, waiting while one of their number walks to the portal and back, to pay for the entire installation of such equipment. Causes of accident and delay cannot always be foreseen, it is true, but they can be met promptly and further damage to men and property can be prevented by the use of the telephone; that these advantages are appreciated is shown by the fact that a majority of the tunnels and adits examined in the field were so equipped.

The type of telephone-equipment should be carefully chosen, because every telephone is not suited for underground use. For use in tunnels it must be water-proof, dust-proof, and, since to be useful it must be placed as near the heading as possible, it must be designed to withstand the frequently recurring concussions of blasting. The most successful types of mine telephones meet these conditions by placing the mechanism in a heavy metal casing, in such a way that the essential parts shall be instantly accessible upon opening the outer door, but shall be tightly sealed when it is closed. The more delicate mechanism is guarded further by an inner door, also of iron, and the wires are protected so that water cannot enter the casing. The bells must necessarily be placed outside, but they are protected by a metal hood, which, however, does not prevent their being heard for a considerable distance.

The telephone line for tunnel work is somewhat simpler than a similar line on the surface, because no poles are required and the wires can be strung from ordinary glass or china insulators fastened to plugs in the roof or to light cross-timbers. Common bare iron wire can be used, but much better results are obtainable where rubber-covered wire is employed, and for the same reason a full metallic circuit is desirable, although the telephone may be operated with only one wire by using a ground connection for the return. But since the usefulness of a telephone system is measured entirely by its reliability, the best is in the end by far the cheapest.

It is not desirable to place the telephone nearer the heading than several hundred feet, not only because of the concussion,

but also because of the noise. While this arrangement is convenient for any one in the tunnel desiring to call up the office, it makes it more difficult and sometimes even impossible to secure any response to a call originating on the surface. To obviate this difficulty, the use of an extension loud-ringing call-bell is recommended, which, if placed behind a jutting rock or in some similar protected position, apprises the foreman at the heading instantly of any call at the telephone. Such a bell should be connected with the telephone circuit by a flexible insulated cable mounted upon a reel in such a way that the bell may be advanced regularly to keep pace with the tunnel progress and need never be further than two hundred feet from the heading. When the cable is extended to full length, perhaps 1,000 feet, the telephone should be advanced to a point as near the heading as possible and the extra cable reeled up once more.

INCIDENTALS

Among the many devices used to save time and promote efficiency underground, those of the simplest are the hose supporter and the drill rack, both of which can be made readily by any tunnel blacksmith. The former consists merely of two telescoping pieces of iron pipe, the length of each being about three-fourths of the width of the tunnel. In operation the hose is placed over the pipes, which are then extended until their pointed ends fit into convenient niches on either side of the tunnel near the roof; the pipes are clamped into position firmly by a threaded key which is provided for this purpose. By using two or three of these spreaders the hose are kept clear of the shoveler, who is thus saved no little trouble and annoyance and is able to work to better advantage. The latter device is simply a rack for separating different lengths of drill steel. A satisfactory form consists of an A frame made of 4-inch by 4-inch timbers, into which iron pegs are driven at convenient intervals. The segregation of the sharp drill steels on this rack enables the helper to pick out the proper length with assurance and dispatch.

CHAPTER XI

DRILLING METHODS

The discussion of methods of tunnel construction in this and following chapters will be restricted chiefly to those employed where the entire cross-section is excavated in one operation. The majority of tunnels and adits driven for mining work, and many tunnels intended for irrigation and water supply, are small enough to be driven in this manner; but in the construction of the larger undertakings, such as are required for railroad or similar purposes, it is customary to drive a pilot tunnel or heading, as it is sometimes called—although the term is also employed to designate the advancing end of any tunnel—in front of the main body of the work which then consists in enlarging the smaller excavation to full size. The latter method, in addition to lowering the average cost of the entire work, since the process of enlarging is much easier and less expensive than that of driving the heading, also gives a valuable preliminary insight into the conditions which must be encountered later by the main tunnel, and enables the constructor to anticipate emergencies and make provision for them in his plans, thus aiding to prevent accidents and loss. Since, however, the scope of this bulletin is to be confined chiefly to mine adits and small tunnels, a discussion of the various phases of the "heading and bench" system cannot be treated here as such, although the methods used in excavating in one operation the entire section of a small tunnel are in most cases applicable to the driving of headings for larger tunnels. Local conditions at each project necessarily modify methods to such an extent that it is impossible to make a general analysis to fit all cases, but the discussion is intended to bring out some of the more important features of the methods employed in the various operations

of drilling, blasting, mucking, and timbering, as they are applied to the driving of mine adits and tunnels.

NUMBER OF SHIFTS

One of the chief advantages claimed for the single drill shift per day method is economy. By having the débris cleared from the heading by the shoveling crew at a separate time, the drill men upon reaching the face are enabled to start immediately to work setting up the machines and preparing to drill the ground; there is therefore no waste of time or labor on the part of these men or the helpers in shoveling out débris preparatory to mounting the drills. This method is especially economical when vertical columns are employed. During the process of drilling the operators and their helpers are not interfered with or hindered in any way by the shoveling crew, and there is therefore a saving of that loss of motion which can hardly be prevented when two crews are working simultaneously in the heading. Moreover, since there is no delay in getting started, it is ordinarily possible to complete the round of holes within the allotted time, and even if this cannot be done plenty of extra time is available without delaying the following shift. The drilling and mucking shifts can be distributed so that there is no loss of time and wages while the men are waiting for smoke and gases produced in blasting to be removed from the tunnel—a matter of cardinal importance where the provisions for ventilation are inadequate. These considerations all go to support the contention that the actual excavation cost per foot of tunnel is lower with this method than with other systems.

On the other hand, by employing a single drill shift the daily progress in driving the tunnel is necessarily limited to the advance gained from the one attack, and therefore the completion of the work must inevitably be delayed. Most tunnels are practically worthless until completed. If their construction is not pushed as rapidly as possible, not only is the capital invested in the equipment, tools, etc., securely tied up much longer than necessary and the cost for interest and the depreciation charges proportionally increased, but there is also a delay in the realiza-

tion of the benefits to be derived from the tunnel, which in most cases is more than sufficient to offset any saving in excavation cost. For example, if an adit is being driven to drain a mine, the extraction of additional ore below water level is greatly delayed; or if the adit is intended to lower the cost of transporting the ore to the surface, the loss on the additional tonnage handled in the old way, owing to the delay in its completion, should be charged against this system of operation. Similarly with an irrigation tunnel, the entire season's crops may be lost from the longer time required to complete the tunnel if it is excavated by the one-shift method. Then again, the cost for administration and many other of the fixed charges are operative during the period of construction, independent of the number of shifts per day, and since the daily progress increases with the additional attacks per day, the proportionate charge against each foot of tunnel driven will be smallest when the greatest number of shifts are employed. Although, owing to a saving of the time and wages of workmen, there is an apparent economy in the cost of excavation by the one-shift method, when factors which reach deeper are considered, it will be found in most cases that the real and ultimate cost of the tunnel will be lowered by methods which make directly for speedier completion.

Greater progress is undoubtedly attained with two shifts per day than with one, and if the work is properly organized there need be but little added excavation cost. It is the usual custom with this system to have the shovelers start work somewhat in advance of the drillers, and to work first at removing the broken rock directly at the face to make it possible for the drillers to set up their machines promptly. At some adits and tunnels where two drill shifts were used, the drilling and mucking took place simultaneously, the drillers themselves attending to the work of clearing out for the set-up. Of these two methods the former is preferable, not only because it economizes the time and exertion of higher-priced men, but also because the length of time when both crews are at work together in the heading—and consequently the inevitable amount of interference and interruption—is thereby lessened. At a few places

three crews of shovelers were required to remove the rock broken by two drilling attacks. This system is obviously expensive because the cost of the extra shovelers must be charged against a footage but slightly, if indeed at all, increased by their efforts, and it entails, for two of the three shifts, the disadvantage of simultaneous work just mentioned; it is therefore not desirable. When it must be resorted to it may usually be taken as an indication that a change which would permit its discontinuance should be made either in the length of the holes drilled and blasted or in some of the other methods of work.

The consensus of usage at tunnels and adits where the best results in driving have been achieved, both in this country and abroad, leads to the conclusion, however, that the three-shift system of attack is the most desirable. This method has a number of opponents who charge against it four chief disadvantages: (1) that time is lost on the part of the drill men in getting the machines set up and in operation; (2) that the greater number of men crowded in the restricted space of the heading are in one another's way, and therefore unable to work to the best advantage; (3) that the men must be paid for time wasted in waiting for the smoke and gases produced in blasting to be cleared from the heading; (4) that the system makes no provision for delays due to adverse conditions. As will be pointed out shortly, the time consumed in setting the machines up can be made negligible by the use of suitable methods of mounting and by properly directing and blasting the round of holes. A certain amount of crowding is, of course, unavoidable, but it is more than offset by the gain in efficiency from the various incentives which can result only from the three-shift method. To begin with, the shovelers have constantly before them the necessity of removing the waste rock before the drillers have finished their work, and are therefore unconsciously speeded up by the competition. At the same time the drill men endeavor to have their holes finished by the time the tunnel is cleared in order that no delay may be attributed directly to them. And both crews are inspired to better work by the knowledge that a competing shift is to follow immediately

upon their heels, taking their places and performing similar work. Then, too, after the holes are drilled the extra men from the shoveling crew are of great assistance in taking down the machines and removing them, together with the mountings, hose, tools, and other articles that must be taken to a place of safety during blasting. As to the time wasted in clearing the tunnel of smoke, if it is properly and adequately equipped with ventilating apparatus this operation should require little more than fifteen minutes—just long enough for the men to eat their lunches, which time would have to be lost at any rate. Delays of course cannot always be prevented, but the men are encouraged by rivalry to reduce these to the minimum, knowing that their work is to be compared with that of the shift to follow. These answers to the various objections are in no sense theories, but are deductions from actual observation and a study of conditions as they existed at tunnels and adits where some of the most efficient work in this country was being performed.

The ideal results of the three-shift method, to be sure, are obtained only through perfected organization and good management, but they utterly disprove the contention that efficient work is not possible under those conditions. That it is capable of the most rapid progress has never been gainsaid, and with proper handling the actual cost of excavation per tunnel-foot need be but little if at all greater than with other methods; while, as has been shown, in most cases the system affording greater speed is within limits ultimately the more economical one. For these reasons, unless the conditions are indeed exceptional, the employment of three drilling shifts per day is recommended, and the discussion of other phases of tunneling methods which follow will, unless otherwise noted, be predicated upon the assumption that three drilling shifts are being employed.

MOUNTING

American tunnel practice is almost equally divided between the horizontal-bar and the vertical-column methods of drill mounting. The former consists essentially of an iron pipe, 4 to 6 inches in diameter, a little shorter than the average width

of the heading, and provided with a solid head at one end and a jackscrew with a capstan head at the other. The latter, which is rarely employed with more than two drilling attacks per day, is usually provided with a yoke and two jackscrews at one end, and its length is somewhat less than the height rather than the width of the heading. In several notable European tunnels a drill carriage was employed, however, so that a discussion of this method of drill mounting should not be omitted.

The system employed with horizontal cross-bar method of mounting rock drills can perhaps be best illustrated by a description of the procedure at the Laramie-Poudre tunnel. As soon after the blasting as ventilation permitted (ordinarily ten to fifteen minutes), the workmen returned to the face from a position of safety 1,500 to 2,000 feet away, bringing with them an ordinary tunnel car containing the cross-bar, drilling machines, tools, hose, etc. The three drillers, with the assistance of the foreman, first removed any loose rocks from the roof or walls which might fall later and possibly cause injury. This accomplished, they next cleared a space in the top of the rock pile, for two or three feet back from the face of the tunnel and perhaps four or five feet from the roof, in order that they might have room to work when drilling. Because of methods of blasting especially employed for this purpose, the rock pile usually occupied but a small part of this space, so that ordinarily but little work was required to clear it out. In the mean time, the helpers were expected to unload the bar and machines from the car, placing them on the rock pile conveniently at hand, and to connect the hose to the air and water mains. As soon as a proper space was cleared out, the bar was picked up by the drillers and helpers and held in position transversely across the tunnel at a measured distance from the face and roof, as directed by the foreman, where it was blocked, wedged, and finally screwed as tightly as possible in place. The drill men then placed the machines upon the bar and started drilling as soon as the helpers completed connecting the hose to the drills. The necessary holes having been drilled from this position of the bar, and the waste rock having been removed in the mean

time by the shovelers (an operation which was carried on simultaneously with drilling and which ordinarily was accomplished before the drillers had finished), the machines were taken off, the bar was lowered and set up again about eighteen to twenty-four inches from the floor, the drills were replaced, and one or two holes were drilled by each machine from this position of the bar. The machines and the bar were then placed in a tunnel car and removed from the heading during the blasting. This method, sometimes slightly modified, was used at several other tunnels and adits with almost equally good results.

The procedure with the vertical-column method of mounting is similar to this in some respects, but there are also some important distinctions aside from that of upright position. Owing to the vibration produced by the drills, neither method of mounting will give satisfaction unless the bar is firmly jacked against solid rock. The amount of vibration is intensified and the need of a substantial foundation is much greater in the case of the vertical column, because the drills are usually mounted on cross-arms projecting from the columns at right angles, thus affording a leverage for any movement of the drill. It is therefore necessary to remove all of the waste rock from the space immediately in front of the face of the tunnel prior to drilling in order that the foot of the column may rest upon the solid floor, which, at the two or three tunnels where this method was employed with the three-shift system, caused considerable delay even under normal conditions. But in the majority of places where this method of mounting was employed not more than two drilling attacks were attempted per day, and the extra work of clearing away was performed by the crew of shovelers before the drillers started work.

The best results with the carriage mounting for drills were obtained during the construction of the Loetschberg tunnel through the Bernese Alps. In the first type of carriage employed there, the horizontal bar carrying the drills was mounted at the end of a steel beam which was pivoted to a truck and counterbalanced at the other end by a heavy weight. Before this carriage could be brought sufficiently near to the face,

even with the long beam, for the cross-bar to be jacked in position, it was necessary to clear quite a large passageway through the center of the rock pile down to the floor. In doing this, part of the material was carried away, and the remainder piled on either side of the tunnel to be carried away during drilling. When the passage was finished, however, the carriage, with the cross-bar and drills mounted upon it and extending longitudinally, was quickly rolled to the face, the bar swung around and jacked into position, and the drills were at once started to work.

This carriage was superseded by one which abolished the counterbalanced beam and carried the drill bar directly upon a short post mounted on the truck. With this device practically all of the broken rock had to be removed from the heading before the carriage was brought to the face, after which, however, the drills started promptly at work.

One of the most important factors to be considered in choosing a method of mounting for tunnel work is the time required to get the drills in operation after blasting, including not only the actual time employed in setting up the necessary apparatus, but also the time consumed in the preparatory work of clearing away débris. The time spent in waiting for the smoke to clear is of course independent of the method of mounting, and can therefore be ignored in this connection. With the horizontal-bar system used at the Laramie-Poudre tunnel, the time normally employed in mucking back was rarely more than fifteen to twenty minutes. Jacking the bar in place occupied from five to ten minutes, and attaching the drills and making the water and air connections usually required from ten to fifteen minutes. The entire operation thus consumed under ordinary conditions from thirty to forty-five minutes, but it was not at all unusual, where circumstances were favorable, for the drills to be in operation within twenty or twenty-five minutes from the time the drill men reached the heading. At other tunnels and adits using this system the time required for similar work was reported as from thirty to sixty minutes. Owing to the much greater amount of material to be cleared out when the vertical-column

method is employed, the time consumed in getting the drills in position to start work at adits and tunnels where the three-shift system was used ordinarily ranged from two and a half to four hours, and even under the most favorable circumstances was rarely less than two hours. The time spent in the Loetschberg tunnel in removing the waste rock was approximately one and a half hours with the first type of carriage used and from one and a half to three hours with the later model; but in order to accomplish this, nearly twice as many men were employed at the work as are usually found in American tunnel headings. After the Loetschberg tunnel was cleared of the necessary amount of débris, however, the machines could ordinarily be started in from five to ten minutes.

Aside from the question of the time consumed in clearing, the amount of waste to be removed has another bearing on the problem of choosing a mounting. In order that there may be no delay in getting the drills at work, usually the attempt is not made to remove the waste rock entirely from the heading before the mountings are set up, much of it being merely shoveled to one side and removed later. This preliminary work is often performed by the drill men, especially with the three-shift system; and where (as in the case of the vertical-column method) there is a great deal of it to be done, by the time the men have the machines set up and are ready to start drilling they are pretty well tired out and consequently cannot work so rapidly and efficiently in drilling the required holes. Even if the work is performed by the regular shoveling crew, these men certainly are not stimulated by the knowledge that they are performing dead work and that every shovelful handled in clearing back must be moved again later. This disadvantage obtains not only in the three-shift system, but in many cases in which two shifts are employed, and the shoveling crew start ahead of the drill men and commence work clearing away the face for a vertical column set-up. The horizontal-bar and, to a lesser degree, the drill-carriage methods have the advantage of requiring a much smaller proportion of duplicated work.

The adaptability of the mounting for the work required of

it after the drills are in operation is another factor to be reckoned with. The advocates of the vertical-column method claim that it enables the holes to be placed to better advantage, and this is quite truly the case where piston drills are employed. But hammer drills mounted on a horizontal bar can place the holes just as effectively, if not more so. But with either type of machine the drill carriage is badly handicapped. It was discovered with those used in the Loetschberg tunnel—and the same disadvantage was experienced at an adit in this country where a similar drill carriage was tried and soon abandoned—that it was impossible to point the inclined holes in such a way as to secure the maximum efficiency from the explosive used. Therefore, in order to make the holes break to the bottom it was necessary to use heavier charges of explosive, and the holes were not drilled as deeply as they might otherwise have been. The shallower holes made it necessary to spend a greater percentage of the day's labor in the unproductive preparatory work of setting up and tearing down the drills, and increased the opportunities for delays in blasting. Then, too, it is impossible with one set-up of a horizontal bar, such as was used in the carriage method of mounting, to make the holes near the bottom of the tunnel sufficiently horizontal to secure an even floor, necessitating trimming and causing trouble in maintaining the proper tunnel grade.

The fact must not be overlooked, however, that with the carriage method drills are subject to less wear and tear because they are kept on the bar continually and are not thrown around on the floor and muck-pile. When this is permitted the drills are apt to become filled with sand, grit, etc., and because of friction and abrasion, the cost of repairs is increased. Nor should the facility in changing to a new hole possessed by the horizontal bar and the drill carriage be disregarded. When these methods of mounting are employed, all that is necessary in starting a new hole is to slide the drill along the bar and clamp it in place, but with the vertical column not only the machine, but the cross-bar as well, requires adjusting; since the adjustment is a vertical instead of a horizontal one, the entire

weight of both drill and cross-arm must be lifted or sustained at nearly every change.

Taking, then, all of these factors into consideration, the horizontal bar proves to be the method of mounting drills best adapted for tunnel work. Its use enables the drills to be put in operation with the least loss of time and by the smallest number of men. It requires the rehandling of the minimum amount of waste rock, so that the drill men are not fatigued before they start drilling or the shovelers disheartened by dead work. It permits directing the holes in such a way that the maximum strength of the explosive is utilized, drilling deeply so that too great a portion of the time need not be spent in preparatory work, and placing the holes to insure the breaking of the roof and floor smoothly and at the desired grade. It is especially adapted for use with the more rapid-drilling hammer machines and lends itself readily to removal when necessary. In common with the vertical type it is subject to the danger of allowing grit to become lodged in the machines, but this can be partially prevented by care in handling. These considerations render the use of the horizontal bar highly desirable where an efficient method of mounting drills for tunnel work is desired.

NUMBER OF HOLES

Any determination of the proper number of holes to be used in driving a tunnel or adit of a given size is dependent upon several factors. A large number of holes in which a greater charge of explosive may be placed expedite the operations of driving, because the heavier blast tends to hurl the rock farther away from the face, and thus not only saves time in setting up the machines, but also gives the shovelers more room and enables them to work to better advantage on more widely scattered material. But, at the same time, holes that are not strictly a necessity entail an extra expense not only for the explosive used in them, but also for the time required in drilling. This is especially true in those cases in which the drilling work requires more time than the operation of removing the rock, and hence any extra holes would delay both crews. If the proper

NUMBER OF HOLES USED IN DRIVING TUNNEL HEADINGS

Tunnel	No. of holes	Rock	Approximate area of heading, sq. ft.	Square feet of heading per hole	
				Sedimentary rocks	Igneous rocks
Burleigh	16	Granite and gneiss	42	......	2.6
Buffalo Water	22	Limestone	120	5.5	......
Carter	10–11	Gneiss, granite, and porphyry	41	......	3.7 – 4.1
Catskill Aqueduct:					
Rondout	22	Limestone, sandstone, and shale	120	5.5	......
Wallkill	24	Shale	120	5.0	......
Moodna	24	Sandstone and shale	120	5.0	......
Yonkers	21	Gneiss	120	......	5.7
Central	18–24	Gneiss	35	......	1.5 – 1.9
Chipeta	15–19	....	57	......	3.0 – 3.8
Fort Williams Water	14–20	Basalt	35	......	1.7 – 2.5
Gold Links	12	Gneiss and granite	48	......	4.0
Grand Central Sewer	18	Gneiss	40	......	2.2
Gunnison	24	Altered granite	60	......	2.5
Joker	19–21	....	130	6.2 – 6.9	......
Laramie-Poudre	21–26	Close-grained granite	70	......	2.7 – 3.3
Lausanne	15–21	Shale, conglomerate, and coal	85	4.0 – 5.6	......
Los Angeles Aqueduct:					
Elizabeth Lake	25	Granite	145	......	5.8
Little Lake Division	14–16	Medium granite	90	......	5.6 – 6.4
Grape Vine Division	20–21	Hard granite	90	......	4.3 – 4.5
Lucania	25	Hard granite	65	......	2.6
Marshall-Russell	18–20	Granite and gneiss	72	......	3.6 – 4.0
Mission	12–14	Shale and slate	37	2.6 – 3.1	......
Newhouse	19	Gneiss	65	......	3.4
Nisqually	18	Rhyolite	95	......	5.2

NUMBER OF HOLES USED IN DRIVING TUNNEL HEADINGS—(*Continued*)

Tunnel	No. of holes	Rock	Approximate area of heading, sq. ft.	Square feet of heading per hole	
				Sedimentary rocks	Igneous rocks
Northwest Water	22	Sedimentary rock	110	5.0	......
Ophelia	20–24	Granite	80	......	3.6 – 4.0
Rawley	25–27	Andesite	55	......	2.0 – 2.2
Raymond	14	Gneiss and granite	80	......	5.7
Roosevelt	24–26	Hard granite	60	......	2.3 – 2.5
Siwatch	12	Granite	45	......	3.7
Snake Creek	16	Diabase	65	......	4.0
Spiral	21	Limestone	175	8.4	......
Stilwell	16	Conglomerate and andesite	50	3.1	......
Strawberry	16–18	Limestone, sandstone, and shale	50	2.8 – 3.1	......
Utah Metals	12–16	Quartzite	80	5.0 – 6.6	......
Yak	18	Limestone, sandstone, shale, and granite	50	2.8	......

number of holes is being used, the major portion of the rock should be broken into fragments small enough to be shoveled readily, although an occasional boulder, because of the relaxation it affords the workman from the steady grind of shoveling, is said to expedite rather than retard the speed with which the spoil can be loaded into the tunnel cars.

The central factor and starting point, however, in a just determination of this question is undoubtedly the physical character of the rock being penetrated, which is never twice alike in different localities, and it is generally necessary to experiment at first in order to discover what number of holes will indeed produce the best results. Generally speaking, igneous rocks require more holes than sedimentary rocks, but there are wide divergences in both classes. The holes must be more closely spaced for a tough rock that is close-grained and massive than for one that is brittle and easily-shattered, even though it may be harder and more difficult to drill. Bedding or joint planes or joint cracks are of great assistance, and a rock in which they occur will be more easily broken and hence require fewer holes. The preceding table shows the number of drill holes used in American tunnels penetrating different classes of rock.

DIRECTION OF HOLES

Chiefly because of the great influence of local conditions, the arrangement of drill holes is rarely identical at any two tunneling projects. For reasons to be explained later, however, it is customary to drill a part of the holes (called the "cut" or "cut holes") in such a manner that when blasted they will first remove a core of rock from the solid face of the heading, thus decreasing the work to be done by the remaining holes. Practically all of the various means of arranging drill holes in the headings of American tunnels may be summarized as follows into three main types, according to the kind of cut employed.

The wedge or "V" cut is the one most commonly employed in tunneling operations in this country. It consists essentially of several pairs of holes directed toward each other from opposite sides of the heading in such a manner that when properly charged

and exploded they will break out a wedge-shaped core of rock usually extending from the roof to the floor of the tunnel. Figure 58 shows a typical wedge-cut round similar to the one employed in driving the Buffalo Water tunnel. Holes numbered 1 to 8 comprise the cut and were blasted simultaneously by electricity, while 9 to 14 are the side holes, and were next fired together, and 15 to 18 are the back or dry holes and were exploded last. Such a round must necessarily be changed somewhat where the heading is arched or semicircular. Figure 59 illustrates such a round, similar to those used in driving the heading of the large siphons on the Catskill Aqueduct. In this case holes 1 to 6, comprising the cut, were blasted together, followed by holes 7 to 12, which were called relievers, and finally by 13 to 22, which were called trimming holes.

Either vertical columns, as was the case in the two examples just cited, or a horizontal bar may be used to mount the machines when drilling this type of round, but where the majority of the holes are to be drilled from one position of a horizontal bar the location of the holes must necessarily be somewhat modified, although the general arrangement still remains a wedge-cut round. Figure 60 shows such an arrangement, similar to the one employed at the Laramie-Poudre tunnel. Holes Nos. 1 and 2 were called short-cut holes, Nos. 3 to 6 long cuts, Nos. 7, 8, 9, 10, 19, and 20 relievers, 11 to 14 sides, 15 to 18 backs, and Nos. 21 to 23 lifters, the numbering indicating the order of blasting. The lifters, and two relievers (Nos. 19 and 20) which were used only in hard ground, were the only holes drilled from the lower position of the bar. Three machines were employed in drilling this round, and the following table (page 224) shows the holes drilled by each and the order of drilling (lettering the machines A, B, and C from left to right when facing the heading).

A somewhat similar round was used with a horizontal bar at the Rawley tunnel, and there are, of course, many other variations of the V-cut arrangement of holes, but these figures illustrate the principles underlying the more common ones employed in tunnels and adits in this country.

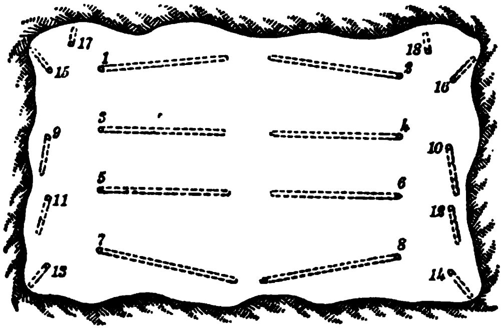

FIG. 58. Wedge-cut round of holes.

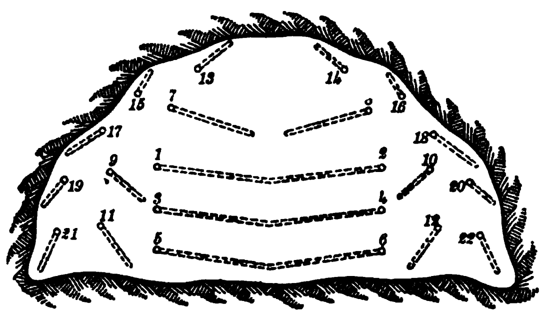

FIG. 59. Modified wedge-cut round for arched heading.

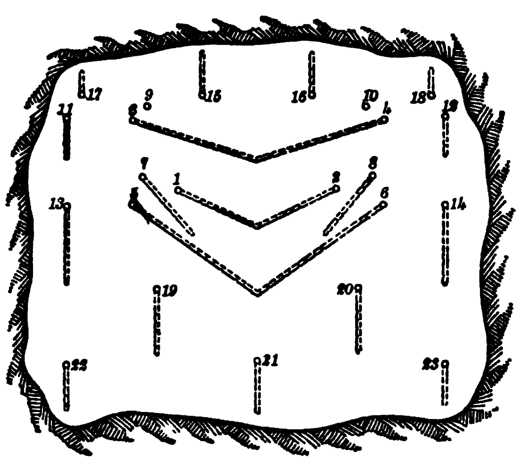

FIG. 60. Wedge-cut round drilled from a horizontal bar.

ORDER OF DRILLING FOR EACH MACHINE AT LARAMIE-POUDRE TUNNEL

	Machine A	Drill-hole numbered	Machine B	Drill-hole numbered	Machine C	Drill-hole numbered
Upper position of bar	1	17	1	16	1	18
	2	11	2	10	2	12
	3	5	3	15	3	6
	4	13	4	9	4	14
	5	7	5	3	5	8
	6	1	–	—	6	2
	7	19	–	—	7	20
Lower position	8	22	6	21	8	23

The second general type of cut frequently employed will be designated as the pyramid cut, consisting usually of four cut holes drilled in such a manner that they meet, or nearly meet, at or near a common point—generally near the axis of the tunnel—and when properly blasted they remove a more or less pyramidal core. Figure 61 shows a round of this type similar to the one employed at the Yak tunnel, in which the cut holes numbered 1 were blasted simultaneously, followed by the remaining holes in the order indicated. In most of the instances observed by the authors, the pyramid cut has been employed with vertical columns, but it can be drilled just as efficiently with the horizontal bar by drilling two or possibly three holes with each machine from the lower set up. Figure 62 shows such a round.

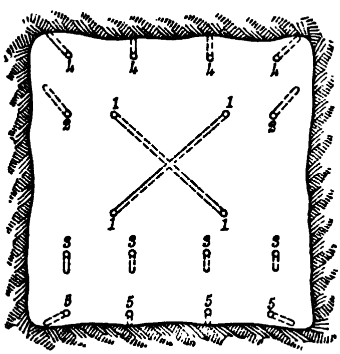

FIG. 61. Pyramid-cut round of holes.

The third type is the bottom or draw cut which was employed at several places visited, the one at the Carter tunnel illustrated in Figure 63 being typical. The holes were blasted in the order indicated, Nos. 1 to 3 comprising the cut.

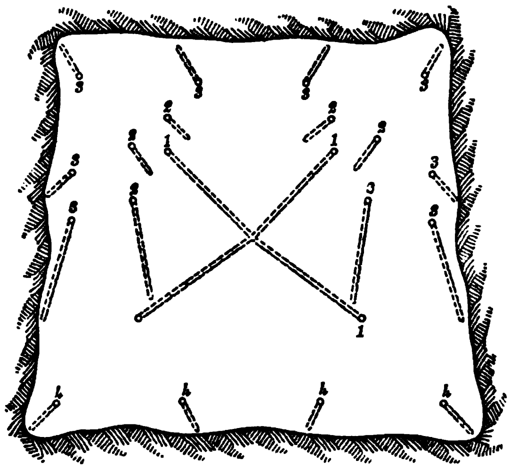

FIG. 62. Pyramid-cut round for use with horizontal bar mounting.

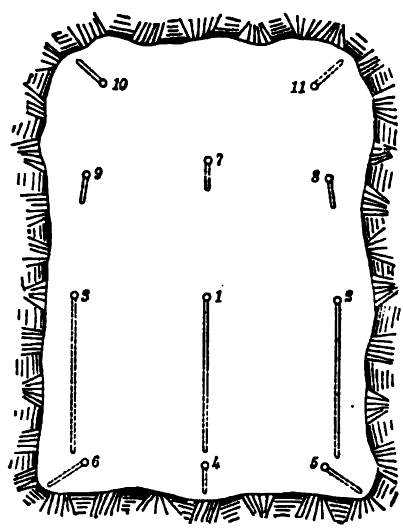

FIG. 63. Bottom-cut round of holes.

It can easily be proved theoretically that where a bore hole is drilled in a homogeneous mass of rock the maximum efficiency can be obtained from a suitable charge of explosive placed in it when the line of least resistance (by which is meant the shortest distance from the charge to a free surface of the rock) is at right angles to the axis of the bore hole, and that the minimum efficiency will be obtained when the two are coincident. And practically, although a homogeneous rock is a rarity and hence the actual results will be influenced quantitatively somewhat by the various features of rock texture such as joints, cracks, fault fissures, bedding planes, etc., the results have been found to agree in the main with the theoretical deductions. It is obvious, therefore, that in the heading of a tunnel or adit where but one free face can be obtained, it is impossible to drill and blast a single hole in such a manner that the maximum efficiency can be obtained from it. But by drilling a number of holes arranged according to any of the preceding systems, and blasting the cut first so as to create more free surface, much better results can be obtained from the holes which remain. It is for this reason that the position and direction of the holes comprising the cut are generally considered the most important feature of the work, the spacing of the remaining holes being admittedly merely a question of having them sufficiently close together to break the rock into fragments of the required size for facile handling.

When the wedge or V-cut is employed, the several pairs of holes should be placed close enough together for them to be of some mutual assistance. This is especially true when the entire cut is exploded simultaneously. What this distance shall be is controlled almost entirely (as in the determination of the proper number of holes) by the character of the rock, its texture, toughness, the presence of cracks and bedding planes, etc. Its determination is often made by the foreman in charge, and if he is a man of wide experience, satisfactory results may follow; but the general efficiency of the work will often be increased greatly if experiments are made at the outset to determine just what combination will give the best results for the particular

rock being encountered. It follows, of course, that such experiments should be repeated whenever a marked change in the nature of the rock is observed.

In order that the line of least resistance may approximate as closely as possible the perpendicular to the axis of the drill hole, the angle between opposite holes in the cut should be as large as can be obtained with any given depth of round. From this it follows that the drill holes should start as near as possible to the opposite sides of the heading; but obviously the full width of the heading cannot be utilized because provision must be made for the feed screw and crank of the drill, which usually extend three to four feet from the face. This works especially to the disadvantage of narrow headings, because in them a greater proportion of the actual width must be sacrificed for this purpose. But with broad headings the marked advantage of a wide angle is easily secured and possibly offers an explanation of the popularity of the wedge-cut system in such cases.

Of even greater importance than the necessity of securing a wide angle between opposite holes is that of drilling them so that they meet, or at least bottom near enough to one another to be detonated simultaneously by the one first to explode. Owing to mechanical reasons, the width of the drill bit, and hence the size of the hole, must be decreased with each successive change of steel, and as a result the hole is necessarily smallest at its bottom end—the place where the explosive is most needed and where it is extremely desirable that the hole should be as large as possible. Omitting from consideration the expedient of chambering (that is, the enlargement of the bottom of the hole by the explosion of a small primary charge before loading it with the main portion of the explosive) which consumes entirely too much time to be considered for rapid tunnel driving, the defect can be overcome to a surprisingly large degree by the simple resort of connecting the drill holes, which concentrates the explosive at the point of the "V." When fuse firing is employed, it is extremely essential that the holes be so directed that they are intercommunicating (or so nearly so that both holes will detonate together) or the desired effect will not be

gained, but when electric firing is employed direct connection, although very desirable, is not so absolutely essential.

But in addition to the mere concentration of explosive thus secured, the combined efficiency of the two charges is much greater than when they are exploded separately. Assuming, again, that the holes are drilled in homogeneous rock and that they make equal angles with the shortest line from their junction to the free face, if both are loaded with identical charges of explosive and detonated simultaneously, their maximum breaking effect will be exerted along the resultant of their combined forces, which in this theoretical case coincides with the shortest distance to the free face (the line of least resistance). Practically, of course, this will be somewhat modified; but it is a well-established fact that where the ground is tough and difficult to break, much better results are obtained when the cut holes are directed and drilled to intersect; although, unfortunately, this is not widely known, as evidenced by the too great number of cases observed in which no attempt was made to connect the cut holes.

Practically the same conditions prevail with the pyramid cut. The number of holes comprising it may vary from three to six or even eight, according to the nature of the ground; and the proper number can best be determined by experiment. It is just as necessary to drill the holes with the widest possible angle between them, and it is even more essential that they meet in a common point, because one of the main advantages of this cut is the concentration of a greater amount of explosive at the narrow apex of the core of rock to be removed. All these advantages are thrown away if the charges of explosive in the different cut holes are not detonated simultaneously.

The bottom cut, as it is usually drilled in practice, although it often enables the attainment of a wider angle between the axis of the drill hole and the line of least resistance, disregards entirely the important advantage to be obtained from connecting drill holes, and this circumstance, in the opinion of the authors, should be sufficient to prevent its use under any but exceptional conditions. For mine adits, however, whose excavation must of neces-

sity provide sufficient head room but whose lateral extent is limited, in which it would be impracticable, if indeed possible, because of the narrowness of the heading, to drill an effective wedge, or a pyramid-cut round, the bottom cut furnishes the only solution of the difficulty. In this event it is recommended that the cut holes be drilled from as near the top of the heading as possible, and directed in such a manner that they will connect with holes that are usually considered lifters, and that both be detonated together.

DEPTH OF HOLES

During the past four or five years there has been some difference of opinion among students of the problems of tunnel driving as to the proper depth for drill holes in tunnel headings. In view of some of the remarkable results attained in driving the Simplon and Loetschberg tunnels, where, as is admitted by every one, the holes were much shallower than those in American practice, the question has been raised whether the holes in tunnels of this country are not drilled too deep. Numerous tables have been prepared in support of this argument, in which it appears that at most of the European tunnels the progress is much greater (in some cases more than double) than that of tunnels in America. But at the same time, consideration is not always given the fact that in many instances these records are in their nature in no wise comparable; for in Europe, at the majority of tunnels thus cited, the work was conducted throughout the entire twenty-four hours of each day, while in America in many instances but two (and indeed in some only one) shifts were employed daily. Then again, the nature of the rock exerts an all-important influence upon progress, and in many cases this has been to the advantage of the European tunnels. A notable example of the influence of the rock encountered is found at the Loetschberg tunnel, where the same methods and practically the same equipment were employed at the different ends, the one at north end working in limestone, and the other in the south end in gneiss and schist. The progress attained at the south end was much less than that of the north, and in some months the

progress in the north end was nearly double that of the south. Other considerations also, especially the amount of labor and the cost of driving, enter into the problem in such a manner as to make it impossible to say (when everything is taken into account) that the greater speed in European tunnels is due solely to the use of extremely shallow holes. That in many instances the holes in American tunnel headings are too deep, however, is equally impossible of denial, and for these reasons a discussion of the factors which enter into the determination of the proper depth of holes is extremely desirable.

One of the chief advantages arising from the use of shallow rounds is (when the holes are properly directed) the increased efficiency obtainable from a given charge of explosive; for, since the width of the heading is for all practical purposes constant, the angle between the line of least resistance and the axis of the bore-hole becomes a function of the depth of round, the width of the angle increasing with shallow holes. This advantage obtains especially with the wedge cut and with the pyramid cut, and it should be a fundamental consideration with the bottom-cut method of drilling the holes. Strangely enough, however, in the Loetschberg and the Simplon tunnels, which are so often cited as examples of the "highly desirable" European practice of using shallow holes, this advantage was almost, if not entirely, thrown away, because the holes were drilled in vertical rows and were nearly parallel to the bore of the tunnel. In such a case the line of least resistance and the axis of the bore-hole are nearly coincident—a condition which results in the production of the least possible efficiency from the charge of explosive; and it cannot be gainsaid even by the advocates of this method that a much greater quantity of explosive than is usual in American practice was required to break the same amount of rock. If to this is added the fact that such a system utterly ignores the advantage to be obtained from connected drill holes by the concentration of explosive at the apex of the core of rock to be removed, there is strong ground for rational suspicion that the extreme shallowness of the holes used in these tunnels was adopted from necessity rather than from desirability; because with this

system of drilling and directing the holes the difficulty of blasting out the rock with deeper rounds could not fail to be greatly increased.

Among other advantages of the use of reasonably shallow holes may be mentioned the fact that such a method allows that the holes be of larger diameter at their further end, increasing their capacity for explosive and enabling its concentration at the point where it is most needed. This is one of the chief factors which makes even possible the European practice of employing extremely shallow holes, but it can hardly be denied that in this case much more effective results in blasting might be accomplished by a change in the direction of the cut-holes. Besides, since, in America at least, the holes are rarely charged with explosive to their full extent, the mass of rock between the ends of the charges of explosive in the different holes and the free face of the heading (which can be considered as a measure of the amount of resistance to be overcome) is not so great with the shallow holes. This fact, or the customary use of relatively heavier charges in shallow holes, may explain, perhaps, why in such cases the major portion of the rock is usually thrown farther down the tunnel instead of being piled high immediately in front of the new face, with the double advantage of making it easier to load the rock and saving time in getting the drills mounted. It is fairly well established, also, that the rock tends to break into smaller fragments where shallow holes are employed. And again, where deep holes are not employed the same care in starting them exactly at a given point is not required, nor is it necessary to direct them with such great accuracy—although, of course, the need of connecting the cut holes must not be overlooked.

The principal and very serious disadvantage in using the shallow-hole round, on the other hand, and one that it is impossible to avoid, is the fact that in order to secure the same daily advance a proportionately greater number of drilling attacks must be made. This results in a waste of time in drilling; for it is possible under ordinary circumstances to drill one hole of a given depth more rapidly than two holes of the same aggregate footage because of the time lost in changing to a new position,

starting, etc. But even granting that the difference in drilling time (perhaps because it is too small, or because in either case the drilling can be completed before the heading can be cleared of débris) is not an appreciable factor, each extra drilling attack required to secure the same progress causes a corresponding loss of time in loading and blasting the holes, in waiting for the smoke and gases to be removed, in clearing the débris from immediately in front of the face, and in setting up the drills, all of which is ordinarily dead work and cannot be avoided. This was seriously felt at the Loetschberg tunnel, because in the endeavor to compensate for it, it was necessary to employ four drills in the heading (6 feet x 10 feet); and as a result the holes had to be drilled nearly straight, with disadvantages already described, because otherwise the drills in the center interfered seriously with the operation of those at the side.

On the other hand, where the holes are too deep, as is sometimes the case in America, the angle between the cut-holes may be so narrow and the mass of rock in front of the charge of explosive may be so great that it will be impossible for the cuts to break bottom on the first blast and thus the entire round is spoiled. The usual remedy in such cases is to blast the cuts separately and not to fire the remainder of the round until it has been ascertained by inspection that the proper depth has been reached by the cut-holes. A certain amount of delay cannot be avoided when this method is employed, even if the holes break to the end, for it is never possible to return to the breast for such inspection immediately after the cuts have been detonated. But when the cut-holes fail to break, the delay is greatly increased because the remaining portions must be cleaned out, reloaded, and fired, with an additional delay in waiting for the smoke to clear.

This system was used at one of the Colorado tunnels, which at the time of first examination was being driven through some very tough rock, employing a round of holes slightly deeper than the average width of the heading. Holes of this depth had given satisfactory results in the somewhat more frangible ground previously penetrated, the round being drilled and blasted in an

eight-hour shift without difficulty; but upon striking the harder rock it became necessary to blast the cuts separately, and more often than not to reload and shoot them for the second and occasionally for the third time, the cycle being lengthened to about ten hours, while several times at least fourteen hours were needed. If three drilling shifts had been employed at the time, such a condition would have been fatal; but since but two attacks were being made the difference was not so noticeable, though even in this case the cost of the extra explosives required and the overtime wages of the men added a considerable amount to the expense of the tunnel work. Shortly after the first examination of this tunnel by the authors, however, the depth of the rounds was reduced to about 75 per cent. of the width of the heading. This made it unnecessary to load and shoot the cuts separately, and instead of getting two seven-and-one-half-foot rounds in from twenty to twenty-two hours, by working three eight-hour shifts it was possible to drill and blast four, and sometimes five, five-foot rounds per day, thus increasing the daily tunnel progress from fifteen to nearly twenty-three feet with but a very small extra cost for labor. The consumption of explosive which was a very considerable item with the old system was also decreased fully 25 per cent., and the total cost of the tunnel per foot was greatly reduced.

The disadvantage of too deep holes was strikingly brought out in the construction of the Laramie-Poudre tunnel. During the first part of the work a ten-foot round was drilled in a heading 9½ feet wide, but the round was later changed to one of 7 feet in depth with much better results. To be more specific, during the seven months from April 1, 1910, to October 31, 1910, at the east end of the tunnel, 3,171 feet were driven, an average of 453 feet per month, using a ten-foot round; but during the next 8⅘ months, from November 1, 1910, to July 24, 1911, when the tunnel holed through, 4,798 feet were driven, or an average of 545 feet, with a seven-foot round. This is an increase of over 20 per cent., in spite of the fact that the higher speed was made when the work was at a greater distance from the portal; and, since there was no essential change in method,

equipment, or in the character of the rock penetrated, it is attributable solely to the use of shallower holes. When the ten-foot holes were employed to secure an advancement of 8½ to 9 feet, it was unusual to be able to drill and blast more than two rounds in twenty-four hours, and oftentimes not so many, as the average of 14½ feet daily testifies; but with the seven-foot round not only could three attacks be made, advancing on an average 6½ feet per attack, but a comfortable margin of time was left to provide for delays and under favorable conditions this extra time meant extra footage. Thus in March, 1911, the American hard-rock record of 653 feet, or over twenty-one feet per day, was established. This advantage of being able to complete an entire cycle of operations during a single shift should be given the weight in the problem it deserves. If crews of men could be found who would work as well without rivalry and without special incentive to push the work, it might be perfectly feasible to choose a depth of round that would require ten, or even twelve, hours to put it in; but under the present working conditions, where it is necessary to have some accurate measure of the work performed by each crew, a round is required for which the entire cycle can be completed during a single shift, with a sufficient margin of safety to provide for any ordinary delay.

It is, of course, impossible to set any definite standard or guide for the proper depth of hole which will be applicable to all cases. There are too many variables influencing the result. The proper depth can only be and must be determined by experiment in each individual case. But from an extended examination of American practice, investigating carefully the results obtained from the methods employed, from a careful analysis of European practice as far as could be found in published accounts, and from a study of all the available modern authorities, the authors are of the opinion that for the majority of cases the proper depth of drill-hole, the one which most equitably balances the advantages and disadvantages inseparable from the problem will be found after careful experiment to be a depth from 60 to 80 per cent. of the width of the tunnel heading. The following table gives an analysis of American practice in this respect:

	Type of cut	Height of heading	Width of heading	Average depth cut-holes	Average depth other holes	Average depth round drilled	Percentage average depth to width of heading	Rock
Buffalo Water	Wedge	8	15	8	7	7	46.5	Limestone
Carter	Bottom	7½	5½	9	8	8	106*	Gneiss, granite, and porphyry
Catskill Aqueduct:								
Rondout	Wedge	8	14	10	8	8	57	Limestone, sandstone, shale
Wallkill	Wedge	8	14	12	10	10	71.5	Shale
Moodna	Wedge	8	14	10	8	8	57	Sandstone, shale
Yonkers	Wedge	8	14	8	6	6	48	Gneiss
Central	Wedge	7	5	8	7	7	140	Gneiss
Fort Williams	Bottom	6½	5	6	5	5	77*	Basalt
Gold Links	Bottom	8	6	6	5	5	62.5*	Granite and gneiss
Gunnison	Wedge	6	10	7	6	6	60	Altered granite
Joker	Wedge	11	12	10½	9	9	75	
Laramie-Poudre	Wedge	6½	9½	8	7	7	74	Close-grained granite
Lausanne	Wedge	8	12	8	7	7	58	Conglomerate shale and coal
Lucania	Wedge	8	8	9	8	8	100	Hard granite
Marshall-Russell	Pyramid	9	8	10	9	9	112	Granite and gneiss
Mission	Bottom	7	5	8	7	7	100*	Shale and slate
Miss'n (hard gr'd)	Pyramid	7	5	8	7	7	140	Sandstone
Newhouse	Pyramid	8	8	6½	5½	5½	69	Gneiss
Nisqually	Bottom	11	9½	8	6½	6½	59*	Rhyolite
Northwest Water	Wedge	10	13	10	9	9	69	Sedimentary
Ophelia	Wedge	9	9	7	6	6	67	Granite
Rawley	Wedge	7	7½	9	8	8	106	Andesite
Raymond	Wedge	9	9	12	10	10	111	Gneiss and granite
Roosevelt	Wedge	6	10	7	6	6	60	Hard granite
Siwatch	Bottom	7½	6	5	5	5	67*	Granite
Snake Creek	Wedge	6½	9½	6½	5½	6	63	Diabase
Spiral	Wedge	10	16	12	10	10	63	Limestone
Stilwell	Wedge	7	7	6½	6	6	86	Conglomerate and andesite
Strawberry	Wedge	6	8	7	6	6	75	Limestone, sandstone, and shale
Utah Metals	Bottom	8	10	6½	6	6	75*	Quartzite
Yak	Pyramid	7	7	5	4	4	57	Limestone, sandstone, shale, and granite

* The height of the heading, instead of its width, is considered in this ratio when the bott.m cut is employed.

CHAPTER XII

BLASTING

AMMUNITION

To be suitable for use in tunnel work, as distinguished from surface blasting operations, an explosive should not produce any great amount of poisonous gases and should not easily, if at all, be affected by moisture. In common with other usages, a substance is required here that is stable in composition and not rapidly deteriorated by frequent changes of temperature or other causes; it must not, as, for example, is the case with liquid nitroglycerine, be so sensitive to shock that safe transportation and handling are wellnigh impossible. Although under some circumstances, especially in tunnels that are not wet, an explosive called ammonia dynamite can be and is employed on rare occasions, the one which best fulfills the necessary requirements and the one which is almost universally used in tunnel work is known as gelatine dynamite.

Gelatine dynamite is a combination of a certain amount of blasting gelatine (varying according to the strength desired) and a suitable absorbent. The former is made by adding a small percentage of gun-cotton (nitrocellulose) to liquid nitroglycerin, thus producing a jelly-like mass that has greater explosive qualities than either of its constituents, but which is much less sensitive to shock than nitroglycerine. The absorbent is usually some combustible material (wood pulp is frequently employed) to which has been added a sufficient amount of sodium nitrate to supply the necessary oxygen for its combustion. By the use of such a combustible absorbent, instead of the inert one formerly employed with straight nitroglycerine dynamite, the gases generated by the burning of the wood pulp add to the volume produced by the detonation of the explosive constituent, and the extra heat generated in this combustion adds greatly to the

total intensity of the reaction. Ammonia dynamites, which are a somewhat more recent discovery, consist of a combination of ammonium nitrate and nitroglycerine absorbed in a so-called "dope" similar to that just described. The following tables* show typical compositions of commercial samples of these two kinds of dynamite:

GELATINE DYNAMITE

Ingredient	Strength						
	30%	35%	40%	50%	55%	60%	70%
Nitroglycerine	23.0	28.0	33.0	42.0	46.0	50.0	60.0
Nitro-cellulose	0.7	0.9	1.0	1.5	1.7	1.9	2.4
Sodium nitrate	62.3	58.1	52.0	45.5	42.3	38.1	29.6
Combustible materials†	13.0	12.0	13.0	10.0	9.0	9.0	7.0
Calcium carbonate	1.0	1.0	1.0	1.0	1.0	1.0	1.0

† Wood pulp used with 60 and 70 per cent. strength; sulphur, flour, wood pulp, and sometimes resin used in other grades.

AMMONIA DYNAMITE

Ingredient	Strength				
	30%	35%	40%	50%	60%
Nitroglycerine	15	20	22	27	35
Ammonium nitrate	15	15	20	25	30
Sodium nitrate	51	48	42	36	24
Combustible materials‡	18	16	15	11	10
Calcium carbonate or zinc oxide	1	1	1	1	1

‡ Wood pulp, flour, and sulphur.

For further discussion of the nature and composition of explosives, which is hardly within the province of this book, the reader is referred to various publications of the Bureau of Mines; they may be had upon application to the Director, Bureau of Mines, Washington, D. C.

The harmful gases usually resulting from dynamite are carbon dioxide and carbon monoxide. Although the former will

* From a paper by C. T. Hall before American Institute Chemical Engineers, Washington, D. C. Meeting December 20, 1911.

not support respiration, and when present in sufficient amount may cause unconsciousness and even death from strangulation, it has no very injurious effects when sufficiently diluted. The latter, however, is not only exceedingly dangerous, but its effects are also cumulative; indeed if air containing even a very small amount of it is breathed for any length of time, serious and often fatal results will follow. The fact that gelatine dynamite (with the possible exception of ammonia dynamite, which approaches it very closely in this respect) produces under proper conditions the least amount of carbon monoxide is one of its chief advantages for use in tunnel work. Even with this explosive, however, if the cap is not strong enough to cause a complete detonation, and even more especially when the dynamite burns rather than explodes, much greater amounts of carbon monoxide are formed; in addition there are many other harmful gases produced, among which may be mentioned the dangerous peroxide of nitrogen and hydrogen sulphide, the former of which is especially virulent.

The following table shows the results of tests conducted by the Bureau of Mines concerning the kind and amounts of gases produced by the detonation of samples of various kinds of commercial dynamites. In making the tests a charge of 200 grams (approximately 7 ounces) in the original wrapper was exploded in a Bichel pressure-bomb and the gaseous products retained and analyzed:

GASEOUS PRODUCTS FROM EXPLOSIVES

Kind of explosive	Carbon dioxide	Carbon monoxide	Oxygen	Hydrogen	Methane	Nitrogen	Hydrogen sulphide	Volume of gas (liters)
40% straight nitroglycerine dynamite.	27.3	26.9	0.0	18.0	0.4	27.4	....	88.5
60% straight nitroglycerine dynamite.	22.2	34.6	0.0	23.2	0.8	19.2	....	128.9
40% strength gelatine dynamite.........	50.8	3.0	0.0	1.8	0.8	39.5	4.1	60.3
40% strength ammonia dynamite...	41.4	3.8	0.0	3.1	0.8	45.5	5.4	65.6
FFF black blasting powder (300 grs.)..	49.7	10.8	0.0	1.8	0.6	28.4	8.7	67.8

A further distinctive feature of gelatine dynamite, winning for it the advantage over ammonia dynamite for most tunnel work, consists in its practically waterproof quality, a condition largely due to the insolubility of the blasting gelatine which can be freely immersed in water with but little if any of it dissolving. Ammonia dynamite, on the other hand, being hygroscopic, has a great affinity for moisture and hence not only cannot be used in wet work (or even in damp work when it is necessary to split the original paraffined paper covering), but greater care must be used in selecting a dry place for storing it.

Gelatine dynamite is somewhat less sensitive to direct shocks than other dynamites, and unlike them the sensitiveness does not increase with the strength; much stronger detonators must therefore be used even with the higher grades in order to insure complete detonation. This fact is often not sufficiently appreciated by practical mining men, many of whom are not aware of the greater ultimate economy obtainable if the more powerful, although somewhat higher-priced, detonators are used with gelatine dynamites.

The strength of nitroglycerine dynamites as they are made to-day is generally rated according to the percentage of their nitroglycerine content, in spite of the fact that both the volume of gases and the temperature (and hence the disruptive force) are augmented somewhat by the combustion of the absorbent material. Although 40 per cent. is the strength most generally employed, they may be obtained in the following grades: 15, 17, 20, 25, 30, 33, 35, 40, 45, 50, 60, 70, 75, and 80 per cent. In the ammonia dynamites a portion of the nitroglycerine is replaced by ammonia nitrate, but, as will be seen from the table on page 237, the rated strength of this dynamite is nearly the sum of the percentages of these two constituents. Ammonia dynamite is prepared in the same grades as nitroglycerine dynamite, between 25 and 60 per cent. Owing to the strength of the blasting gelatine being greater than either of its constituents, the rated strength of gelatine dynamite is somewhat greater than the percentage of its explosive element. The usual grades of this dynamite correspond to those of nitroglycerine dynamite

between 35 and 80 per cent., but it may also be procured in "100 per cent." strength.

The proper grade for use at any particular tunnel must be determined solely by local conditions. Such widely divergent results are obtained at different localities when using the same grade of explosive and in rock which, as far as can be determined from its physical appearance and structure, is identical, that it is impossible to be dogmatic even with minute knowledge of local details. Generally speaking, however, a tough, close-grained, igneous rock will require a stronger explosive, while a sedimentary rock, or an igneous rock that has been altered and weathered, or perhaps shattered and broken, can be blasted just as effectively with a lower grade of dynamite. A notable example of the use of an extremely high-grade explosive is that of the Roosevelt tunnel, where in the tough, close-grained, Pike's Peak granite "100 per cent." gelatine dynamite was required before satisfactory results were obtained. This is reported to have been the first "100 per cent." dynamite put to use in tunnel work. In all cases it is advisable to experiment at the beginning of the work with explosives of different strengths in order to determine which grade is best suited for the particular rock being penetrated, and it is, of course, obvious that similar experiments should be repeated whenever, owing perhaps to a change in the character of the rock, the dynamite used fails to give satisfactory results.

The practice of loading the bottom portion of the hole with 80 and even 100 per cent. dynamite and using 40 or 60 per cent. in the remainder is not now uncommon, especially in tunnels and adits in the Western States. It has the advantage of producing a greater disruptive force at the bottom of the hole, where such force is most needed, and at the same time it reduces somewhat the cost of explosives, especially when an excessive amount of lower-grade dynamite had hitherto been required. There is entailed, of course, the trouble of handling two different kinds of dynamite, not only in the heading but in the thawing-house as well. Although in some cases where this procedure was tried the same results might possibly be achieved by the use of shorter

rounds, an alteration in the type of cut, or some other change in method, still it is a very useful practice, especially for exceedingly hard, tough rock.

The following table shows the grades of dynamite employed at various tunnels:

DYNAMITE USED AT VARIOUS TUNNELS

	Kind	Strength	Remarks
Carter	Gelatine	40	Some 80%
Catskill Aqueduct:			
Rondout	Gelatine	60	
Wallkill	Gelatine	60	
Moodna	Gelatine	75	
Central	Gelatine	40	
Gold Links	Gelatine	40	A small amount of 60%
Gunnison	Gelatine	40 and 60	Mostly 60%
Laramie-Poudre	Gelatine	60	Some 100% with the 60% in cut holes
Lausanne	Gelatine	60	
Los Angeles Aqueduct:			
Little Lake	Gelatine	40	Some 25% and some 60%
Grapevine	Ammonia	40	Some 60% and 75% gelatine
Elizabeth Lake	Gelatine	40	Tried 60% & 70% also
Lucania	Gelatine	50	
Marshall-Russell	Gelatine	40 and 80	80% also
Mission	Gelatine	40 and 60	
Newhouse	Gelatine	40	100% with 40% in cut holes occasionally
Nisqually	Gelatine	40	
Rawley	Gelatine	40 and 60	60% in cut holes and lifters
Raymond	Gelatine	40 and 60	
Roosevelt	Gelatine	40, 60 and 100	
Siwatch	Gelatine	40	
Snake Creek	Gelatine	40	Some 35% and some 60%
Stilwell	Gelatine	40	
Strawberry	Gelatine	40	
Utah Metals	Gelatine	40 and 60	
Yak	Gelatine	40	

It is obviously impossible to make any set rule for the determination of the proper amount of explosive to be employed in tunnel work, without special reference to given conditions. There are entirely too many variable factors, governed solely by local conditions, which control the fitness of quality and quantity, and

which cannot be foreseen. Various writers have derived from theoretical considerations formulas for the calculation of the proper charge of explosive for a blast hole, but the application of these rules is limited to other types of blasting, such as quarrying or general mining, and they are not suited to the practical and actual conditions of tunnel work. For this, the determination of the proper amount of explosive is often left to the judgment of the foreman in charge, who, if he be widely experienced, can often produce excellent results; but the proper amount can best be ascertained by a series of experiments in which the effects produced by different quantities of explosive are studied and compared.

It is very essential, however, that the charge of explosive be large enough. If it is too small and the cut-holes fail to break bottom, or the rest of the holes do not blast out their full share of rock, it will be necessary to reload the remaining portion of them; this procedure not only requires fully as much explosive as if the holes had been properly charged in the first place, but also occasions a loss of time and footage, both of which are most expensive. For this reason, in a number of tunnels, it was customary to load the cut-holes nearly to the collar. Although this is perhaps extreme, as far as insuring that the cut-holes break bottom is concerned, the extra dynamite helps to shatter the rock in finer fragments, thus making it easier for the shovelers to handle. Also, since no tamping is usually employed in such cases, a certain amount of the explosive probably acts in that capacity and increases the efficiency of the remainder of the charge. The very common practice of loading the lifters entirely full has a very different object in view—that of throwing the major portion of the débris some distance away from the new face of the heading, thus making it easier for the drill-men to get their machines at work promptly, and by scattering the rock over a greater area the shovelers can attack it to better advantage. Such a practice is highly to be commended.

Data as to the exact amount of explosive actually employed in practice are difficult to obtain, chiefly because at many places

an accurate record of powder consumption is not kept; but figures were secured wherever possible at the tunnels visited. At the Gunnison tunnel an average of nearly 30 pounds of 40 per cent. and 60 pounds of 60 per cent. gelatine dynamite were employed per round. This is equivalent to approximately 5.5 pounds per cubic yard excavated. In driving the south heading of the Elizabeth Lake tunnel, the average for 1909 was 32.09 pounds * of explosive per foot of tunnel, which is equivalent to 6 pounds per cubic yard. This figure, however, includes the dynamite used in trimming, hence it is somewhat higher than the amount actually needed in driving. At the Rondout Siphon, 175 to 200 pounds per round were required to drive an average of 10 feet,† with a heading of approximately 120 square feet area—which is equivalent to 3.9 to 4.5 pounds per cubic yard of rock excavated.

In advancing the heading of the Buffalo Water tunnel, 4.8 pounds of 60 per cent. dynamite were required per cubic yard. At the Laramie-Poudre tunnel, the powder consumption per cubic yard for March, 1911, was 3.9 pounds; for April, 4.7 pounds, and for May, 4.9 pounds. The average on the Little Lake Division of the Los Angeles Aqueduct for May, 1911, was 4.5 pounds per cubic yard. At the Wallkill Siphon the average powder consumption per cubic yard ranged from 4.3 to 4.6 pounds. At the Yonkers Siphon the powder consumption was approximately 4.5 pounds per cubic yard excavated.

The figures for the explosive used in the Simplon and the Loetschberg tunnels are somewhat higher. At the Simplon tunnel the charge was 6.5 pounds per cubic yard,‡ while at the Loetschberg tunnel the charge per round to secure an average advance in the 6.5 by ten-foot heading of approximately 3.5 feet was 53 to 57 pounds.§ This is equivalent to 6.5 to 7 pounds per cubic yard.

* *Mines and Minerals*, September, 1910, p. 102: "The Elizabeth Lake Tunnel," C. W. Aston.

† *Engineering Record*, January 1, 1910, p. 26: "Progress on the Rondout Pressure Tunnel," J. P. Hogan.

‡ Saunders, W. L., Trans. Am. Inst. Min. Eng., July, 1911, p. 515.

§ Saunders, W. L., loc. cit.

The usual means of firing blasting charges, especially in tunnels and adits in the Western States, is by the use of a safety fuse. The term safety fuse originated from the fact that when properly used under working conditions this fuse burns at a uniform rate and does not flash or explode, as was often the case with the means employed for igniting blasting charges previous to its invention; but the term is somewhat misleading, because this fuse is not, nor has it ever seriously been claimed to be, safe for use in gaseous coal mines. The fuse used for tunnel work is universally of the waterproof type, composed of a core of gunpowder surrounded by various layers of waterproofing material. In one sample, examined by the Bureau of Mines, "the core consists of a powder train and one white cotton thread; the inner covering consists of ten hemp threads; the inner-middle covering consists of five fine cotton threads impregnated with an asphaltic composition; the middle covering and the middle-outer covering each consists of a 5/8-inch cotton tape impregnated with an asphaltic composition, and the outer covering consists of a 5/8-inch cotton tape covered with whiting. Each covering of tape is wrapped in reverse order." *

In other samples the hemp threads of the inner covering are replaced by cotton threads impregnated with sodium silicate; the inner middle covering is often omitted; the asphalt composition of the middle covering is replaced by gutta percha; the middle outer covering is also omitted, and intervowen cotton threads are substituted for tape in the outer covering. The weight of powder in different types of waterproof fuse varies from 50 to 220 grains per foot, the majority of which is finely granulated, and will pass through a 60-mesh sieve.

Under ordinary conditions a safety-fuse burns at a uniform rate, with a variation rarely greater than 10 per cent., fast or slow. In European countries the normal rate is approximately thirty seconds per foot. According to tests conducted by the Bureau of Mines on fourteen samples of triple tape fuse purchased for the Isthmian Canal the average rate was determined

* United States Bureau of Mines, Technical Paper 7, p. 7.

FUSE TEST, AUGUST 26, 1911*

AT THE STRAWBERRY TUNNEL

WHITE COUNTERED GUTTA-PERCHA FUSE MANUFACTURED JANUARY 25, 1911

No. of Trial	Length of Test Piece, in Feet	Time			Conditions	Remarks
		Min. Sec.	Sec.	Sec. per Foot		
1	8.10	5:59	359	44.3	Water	Av. = 45.31 sec. ft.
2	8.10	5:47	347	42.8	"	Max. = 49.0″ diff. = 3.69″ = 8.1%
3	8.04	6:15	375	46.7	"	Min. = 42.1″ diff. = 3.21″ = 7.1%
4	8.10	6:32	392	48.4	"	Range = 6.9″ = 15.2%
5	8.10	6:37	397	49.0	"	Range for 8′ = 55.2″
6	8.10	6:16	376	46.4	"	Av. time for 8′ = 6m. 2.5s.
7	25.45	18:9	1089	42.8	"	
8	25.45	17:51	1071	42.1	"	
9	8.10	6:2	362	44.7	Air	
10	8.08	6:0	360	44.6	"	
11	8.10	6:34	394	48.6	"	
12	8.10	6:1	361	44.6	"	
13	8.10	5:55	355	43.8	"	Av. = 45.07″/Ft.
14	8.10	6:4	364	44.9	"	Max. = 43.8″ diff. = 3.73″ = 8.3%
15	8.10	6:35	395	48.8	"	Min. = 41.6″ diff. = 3.47″ = 7.7%
16	22.35	17:35	1055	47.3	"	Range = 7.2″ = 16.0%
17	22.32	16:59	1019	45.7	"	Range for 8′ = 57.6″
18	25.50	17:40	1060	41.6	"	Time for 8′ = 6m. 0.6s.
19	25.50	18:28	1108	43.4	"	
20	25.40	18:50	1130	44.5	"	
21	25.50	18:56	1136	44.5	"	
22	22.35	17:15	1035	46.4	"	
23	22.30	17:12	1032	46.4	"	
24	22.30	15:41	941	42.2	"	
25	22.40	16:31	991	44.2	"	
						Av. = 45.15″/Ft.
						Max. = 49.0″ diff. = 3.85″ = 8.5%
						Min. = 41.6″ diff. = 3.55″ = 7.9%
						Range = 7.40″/Ft. = 16.4%
						Range for 8′ = 59.2″
						Av. time for 8′ = 6m. 1.2s.

* By courtesy of Engineer in Charge.

as 26 seconds per foot for three-foot lengths and 24.5 per foot for fifty-foot lengths. This rate is much slower than that of the fuse commonly employed in Western tunnel work, forty to forty-five seconds per foot being the customary rate of burning for fuse used there, although these figures are not the results of tests. Such a test was made at the Strawberry tunnel, however, with the results shown in table on page 245.

Experiments conducted by the Bureau of Mines * prove conclusively, however, that the normal rate of burning of fuse is greatly changed by a number of conditions. Excess of pressure greatly accelerates it, and if the gases are sufficiently confined the increase may be as great as 300 to 400 per cent. Although as great an increase as this would rarely be obtained in practice, the use of tamping which is too tightly packed or which is impervious to the escaping gases may produce sufficient pressure to increase greatly the rate at which the fuse burns. When fuse is exposed to low temperature for a short time the rate is slightly increased, but if it be stored at temperatures below freezing and handled before being warmed, cracks are apt to result in the waterproof composition which will permit the gas to escape, and thus, reducing the normal pressure, retard the speed of the fuse. Storage at high temperatures, however, causes a marked retardation which is apt to cause delayed shots and misfires, and fuse should, therefore, never be stored near boilers or other places where the temperature is high. Moisture seriously impairs the efficiency of fuse which should be carefully protected from it. Although the train of powder is covered with a waterproof covering throughout its length, the powder exposed at the end readily absorbs moisture and the cotton or hemp threads in the center act in the capacity of sponges, so that the fuse for a foot or so from the end may be impregnated with moisture. When the fuse is lighted, this water is driven ahead of the fire in the form of steam and delays the burning of the fuse, and, if there is enough of it, sometimes becomes concentrated and extinguishes the fuse entirely. Although twisting and bending

* Technical Paper No. 6.

apparently have but little effect upon the rate of burning, mechanical injury, such as pounding or crushing by falling rock, and abrasion such as might result from the tamping stick when consolidating the charge, greatly increase the rate. The results of these experiments show most conclusively that the greatest care should be taken in the storage and handling of fuse to prevent accidents from premature or delayed explosions.

Detonators or blasting caps consist of a copper cylinder closed at one end and about the diameter of an ordinary lead pencil, into which is packed some dry mercury fulminate and potassium chlorate. When used with a safety fuse, the end of the fuse is inserted in the open end of the copper cylinder, which is then crimped around the fuse by the use of suitable pliers. Under no conditions should anything but the proper tool be used for this purpose, because the fulminate of mercury is extremely sensitive to very slight shocks, and there is sufficient strength in a single detonator to produce disastrous results if discharged accidentally. In some tunnels, more especially those in the Eastern States, the detonators are ignited directly by an electric current. For this purpose, special electric detonators are required in which the fuse is replaced by two suitably insulated copper wires joined at the inside end by a bridge of fine platinum or other high-resistance wire capable of becoming incandescent during the passage of an electric current; these are inserted in an ordinary detonator into which some gun-cotton has previously been placed. Caps

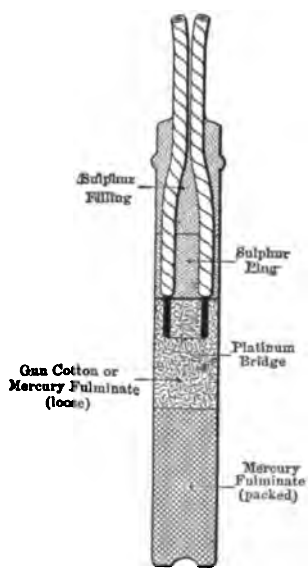

FIG. 64. Section through an electric detonator.

prepared in this manner are called electric detonators and may be secured from the manufacturers with wires of varying lengths, as required.

Figure 64 shows the component parts of one of these detonators.

The strength of detonators is determined by the weight of mercury fulminate they contain, and they are generally designated as triple X, quadruple X, etc.

The following table shows the weights of charge used in the different grades:

WEIGHTS OF DETONATOR CHARGES

Commercial Grades	Weight of charge in grains
3 X—or triple	8.3
4 X—or quadruple	10.0
5 X—or quintuple	12.3
6 X—or sextuple	15.4
7 X—or No. 20	23.1
8 X—or No. 30	30.9

WEIGHTS OF ELECTRIC DETONATOR CHARGES

Commercial Grades	Weight of charge in grains
Single strength	12.3
Double strength	15.4
Triple strength	23.1
Quadruple strength	30.9

The detonator chosen for blasting in tunnel work should be strong enough to produce complete detonation. With straight nitroglycerine dynamite 3 X caps were considered heavy enough, but with gelatine dynamite it is necessary to use much stronger ones because this dynamite is not nearly so sensitive (which makes it, of course, safer to handle). The jelly-like mass of the gelatine dynamite also has a tendency to retard the explosive wave as it passes along the bore-hole, and therefore requires a much stronger initial explosion to carry the wave with the same force through the entire length of the charge. The leading manufacturers all recommend nothing weaker than 6 X caps

for gelatine dynamite. Although 5 X caps have given results which were thought to be sufficiently satisfactory at some tunnels, at others, where a change was made to those of greater strength, the universal experience has been that the better results more than warranted the change, the common report being that "it pays." It is, therefore, here recommended that nothing weaker than 6 X detonators (or double-strength electric detonators) be used with gelatine dynamite, which is practically the only kind employed in tunnel work. In addition to the more effective results produced by the higher-strength caps, the composition of the gases is greatly changed when detonation is not complete, and unsuspected and dangerous constituents may result. As we have seen, with complete detonation the gases are mainly carbon dioxide and nitrogen, with, perhaps, a small amount of carbon monoxide. With incomplete detonation a much greater percentage of dangerous carbon monoxide is formed from the nitroglycerine, and, in addition, the toxic peroxides of nitrogen are produced in larger or smaller amounts, according to varying degrees of completeness of the reaction.

LOADING

There has been much discussion lately regarding the proper position for the primer (as the particular cartridge of dynamite containing the detonator is called) when loading a blast hole; some arguing that it should be the last cartridge to be placed in position, while others claim the only proper place for it is at or near the bottom of the hole. One of the more common arguments for placing it at the top instead of the bottom of the hole is the fact that by so doing one removes the danger of igniting the dynamite from the side-spitting of the fuse, in which case not only is the full efficiency of the explosive not obtained, but the resulting gases are much more virulent and dangerous. For it is obvious that when the fire in the fuse is compelled to travel past the full length of the charge, the danger of the flame bursting through the waterproof covering and igniting the dynamite is a rather serious matter. We are informed, however, by an expert connected with one of the leading explosives manufac-

turing companies, that gelatine dynamites (which, as we have seen, are the kind generally used in tunneling) are less liable to be deflagrated in this manner than any of the others. The objection (which, however, is not applicable when electric detonators are used) is worthy of serious consideration when safety fuse is employed.

A second argument in favor of placing the cartridge last is the fact that the dynamite charge is much more apt to be packed firmly, thus eliminating air spaces which decrease the effectiveness of the explosive. For when the primer is the first or the second cartridge in the hole, the remaining cartridges, and especially the one immediately following, cannot properly be pressed in place with safety, and air spaces are quite likely to be left. This, of course, applies equally to charges detonated by safety fuse or electricity.

A third argument, and one that seems to have been overlooked in the recent discussion, is the fact that the detonation of a charge of dynamite in a bore-hole takes place in a series of steps which follow one another with almost inconceivable rapidity, but which are nevertheless distinct. The first of these is the explosion of the cap, which in turn detonates the dynamite in the primer and causes what may be termed the primary explosion, which in turn is communicated to the remainder of the charge. Although, by employing a strong cap the amount of dynamite detonated in the primary explosion can be greatly increased, it can never be large enough to disrupt the rock completely, the greater force of the secondary explosion being required for this purpose. If, then, the cartridge containing the detonator is placed at the bottom of the hole and fired, the primary explosion consumes the dynamite ineffectually at the bottom of the hole where the full force of the blast should be used; consequently, there is much greater danger of losing the last eight or ten inches of the round, with a consequent decrease in daily advance. It is also claimed that in placing the primer at the bottom, the explosion of the detonator tends to force a certain amount of the charge from the hole; this, however, is debatable. But if the primer is placed at the top, the

primary explosion does not destroy explosive that is essential and the full strength is developed from the remaining portion of the explosive, except in so far as it is influenced by the hindrance to the explosive wave caused by the use of gelatine dynamite previously referred to. And again, by placing the primer at the top, during the primary explosion a certain amount of pressure is developed and the remainder of the charge is, therefore, detonated under that greater pressure, hence its effectiveness is increased. This applies particularly where tamping is employed, and it requires only two or three inches of clay tamping to produce the results. If clay is not used, an extra stick of dynamite placed on top of the primer, which acts partly in the same capacity, is of great assistance.

On the other hand, it is claimed that when the primer is placed on top of the charge the collar of the hole is apt to be knocked off by the explosion of a neighboring charge. There is some question as to whether this really would happen, but if it did it would be a very strong indication either that the hole was misplaced or that it was too heavily loaded; for, as some one has said, "Certainly the collar of a hole is no place for dynamite." And as to the objection that when the primer is placed at the top the fuse is liable to be torn out by flying rocks, the remedy is a very simple one—that of coiling the fuse carefully close up to the hole. And finally, if the wave does not travel with enough force to the bottom of the hole, the matter can be remedied by the use of a strong detonator, or by employing a higher grade of explosive, which would have the double effect of producing a greater primary explosion and of lessening the length of the charge, since less explosive would be required.

It is clearly recognized by the authors that, in some sections of the country at least, the practical miners are accustomed to place the primer at the bottom. But it does not necessarily follow that a practice is correct because the miners so consider it, for many of them also think that dynamite exerts a greater influence downward than in any other direction. Therefore in view of the several considerations outlined above, it would appear that the primer should be placed near the top of the charge.

The use of tamping in tunnel work is also a mooted question. Where low explosives, such as blasting powder having a slow rate of explosion, are employed, tamping is of course absolutely essential in order to confine the gases long enough for their full strength to become effective. But with dynamite whose detonation is extremely rapid, almost instantaneous, it is believed by many persons that tamping is not required, and this belief seems to be warranted by the actual experience that good results can be obtained without its use. A possible explanation for this is the fact that in tunnel work the holes are generally overloaded, and hence the pressure produced by the extra few inches of dynamite charge tends to confine the gases generated by the remaining and effective part of the charge, which is of course also the function of tamping. Another probable reason is that the inertia of the column of air in the bore-hole acts as a partial substitute for tamping of some more solid material. This can be demonstrated by exploding dynamite lying uncovered upon some flat surface in the open, and it is this fact, doubtless, that has given rise to the belief that dynamite exerts more force downward than in any other direction. It is unanimously admitted, however, by experts who have studied the subject, that better results can be secured from any properly loaded hole when more substantial tamping is employed. The amount required depends, of course, upon the rate of detonation of the explosive. With black blasting powder it may be necessary to fill nearly all the remaining portion of the hole in order that the tamping may not be forced out before the reaction is complete and the full strength of the gases produced; but with ordinary charges of gelatine dynamite from two to six inches of well-packed clay will in most cases be fully sufficient.

The use of tamping in tunnel work has several disadvantages which, in the opinion of many, if indeed not a majority, of tunnel men, more than counterbalance any gain in efficiency of explosive from its use. In the first place, it causes delay in loading the holes at a time when every minute is precious. Again, the majority of miners and especially those in the Western States, are strongly biased against it, and any one who has tried to overcome one of

their prejudices will appreciate the difficulty that would be experienced in getting them to use the tamping. While, of course, if tamping were *absolutely* essential to good results, mere prejudice on the part of any one should not be allowed to stand in the way of its adoption, still, as this is not the case, the wishes of the miners are usually deferred to. But a more serious disadvantage of the use of clay or similar material for tamping is the danger attendant upon its removal in case of a missed hole. This is a prolific source of accident. But if the tamping consists of an extra stick of dynamite, as is usually the case in tunnel work, the simple insertion of a primer on top of the unexploded charge is all that is needed to prepare the hole for re-firing. For these reasons, then, although tamping is essential in a bore-hole that is not overloaded, for tunnel work in which it is customary to use more rather than less "powder" than is required, it is not so necessary that clay, sand, or similar tamping be employed.

Among other things to be considered in connection with the loading of a blast hole is the necessity of having the dynamite properly thawed. This is required, not only by due regard for the safety of the men (which alone should be more than sufficient), but also because frozen dynamite cannot be properly packed in the hole, and air spaces cannot, therefore, be avoided, nor is the full force of frozen dynamite developed upon detonation, hence there is a decided loss in effectiveness. It is also very desirable that the cartridges correspond as closely as possible in diameter to the size of the drill hole, and that the paper shall be slit (carefully, of course) along the side with a sharp knife just before they are placed in the hole. This enables the explosive to conform to any irregularities in the shape of the hole. The position of the detonator in the priming cartridge also deserves attention. Experiments have shown that the maximum force from a detonator is developed in the direction of its length. For this reason the detonator should be inserted into the end of the cartridge and not obliquely in one side, as is often the case in tunnel practice. Nor should the fuse project into or be laced through the cartridge because of danger of setting fire to the cartridge, instead of detonating it properly with the cap.

FIRING

When the number of holes to be fired is large, the work of lighting the fuses is generally done by two men, but when there are but few holes in the round, one man is sufficient. When two men do this work it is customary for each man to light the fuse of a corresponding hole (for example, opposite cut holes, etc.), at the same time, each calling out the hole as he lights it. The actual ignition of the fuse (which should be closely coiled and the free end split for one-half to three-fourths of an inch to expose the powder train) is accomplished in various ways. At some places a candle is used, and at others an acetylene lamp. The much better practice, however, is to use a "spitter," as it is called, consisting of a short piece of fuse which has been slashed and partially severed at regular intervals of perhaps one-half of an inch, and the powder train exposed. When the end of such a spitter is ignited the fire travels along it and as it reaches one of the cuts it spits violently out of the side, which if directed toward a fuse is almost certain to ignite it properly. Each fuse should be ignited separately, instead of bunching several of them, and attempting to ignite them all at once, as is unfortunately sometimes done. When it is necessary to protect the ends of the fuse from water by covering it with anything convenient, an empty powder box is frequently employed.

In extremely wet tunnels it is sometimes necessary to use a fuse igniter. One form of igniter that has given excellent results at a number of places where tried consists of a short cylinder of celluloid of the same diameter as the outside of standard fuse, which is closed at one end, and contains a small amount of gunpowder or some similar explosive substance. The other end is slipped over the free end of the fuse which, instead of being split, is cut square, and the igniter fits the fuse tightly enough to be held in place by friction. When being lighted the igniter is, of course, protected from any falling water, and the celluloid is set on fire by a candle or some other flame; since it is unaffected by mere dampness, it burns until the powder charge is reached, when a flash takes place which seldom fails to start the

fuse. These igniters are not expensive, and are exceedingly useful in wet work.

When ordinary electric detonators are employed, the only operations required are those of connecting the wires and passing a current through them by closing an electric-light circuit, or by generating a current in a so-called "battery," which consists of a hand-operated magneto or dynamo. In this case, all the holes so connected are exploded simultaneously, and this is the chief and most serious disadvantage of electric firing for tunnel work. As we have seen, the blasting in tunnel headings, to be effective, must take place in several steps; the cuts first, followed by the relievers, backs, sides, and lifters. Therefore, with electric blasting, although it has the advantage of shooting the cuts simultaneously, it is necessary for some one to return to the heading and connect up the wires leading to the charges in the holes to be fired in each of the succeeding steps; and as it always requires a certain amount of time in order to permit the smoke to clear, and oftentimes no little shoveling is required to uncover wires which have been buried by a previous round, it takes much longer to blast a round in this manner.

Manufacturers of blasting supplies are trying to perfect a delay-action detonator, in order to overcome this defect. This resembles ordinary electric detonators, except that the platinum bridge does not ignite the mercury fulminate directly, but sets fire to a short train of gunpowder inside of the cap, which requires an appreciable, although short time, in burning before it reaches the detonating portion. By making the powder train of two different lengths, two delays are obtained which, if used in connection with a detonator not containing a powder train, enables the blasting to be performed in three stages from a single connection of the wires and from but one closure of an electric current. When using these devices in tunnel work an instantaneous detonator is usually placed in the cut holes, a "first delay" in the relievers, and the "second delay" in the remaining holes. It is unfortunate that these detonators have not as yet been perfected for more than two delays, and this has undoubtedly prevented their more extensive use for blasting tun-

nel headings. For this work, three stages will hardly give satisfactory results, because a fourth stage is essential for the lifters, whose function it is to throw the material broken by the other holes from the immediate front of the new face; and with the horizontal-bar mounting a fifth step is also desirable in order to permit one lifter to go off after the others and throw the material away from the side of the tunnel where the capstan end of the bar is to be placed, thus to afford plenty of room for the operation of the jack bar and permit it to be screwed tightly in place.

There is, however, now upon the market an electric fuse which will permit of the blasting being conducted in almost any number of steps that may be required. It consists, as does the ordinary electric detonator, of a platinum wire bridge enclosed in a metal cylinder by a waterproof composition. In the other end of the cylinder (which, instead of being closed and containing mercury fulminate, is left open) a short section of ordinary safety fuse is inserted, crimped in place, and the joint waterproofed. After an ordinary blasting detonator has been placed upon the other end of this piece of fuse and an electric current is passed through the copper wires leading to the platinum bridge, the fuse takes fire and burns until it ignites the detonator. By cutting off different lengths from these pieces of fuse before inserting them in the blasting caps, any desired number of delays may be obtained from one connection of the wires and one closure of the electric current. This device, therefore, overcomes the one great disadvantage of electric firing.

Chief among the advantages of electric firing is the certainty of detonating all of the cut-holes simultaneously. Although, of course, if two holes are connected they will explode as one, it is impossible to make several pairs of cut-holes, in a wedge cut, for example, explode together when fuse firing is employed. There will always be enough variation in the rate of burning of the fuse to prevent it, no matter how exactly the lengths of the fuses are cut. But when the cut-holes are detonated simultaneously, as can be done with electric firing, each can assist the other with a resulting increased effectiveness from the explosive. It is, of course, true that even with electric delay-

action detonations, holes fired on the first and second delay cannot be made to detonate absolutely simultaneously, and even less so with the electric fuse just described; but this is not so essential, since the work of the succeeding holes does not approximate that of the cuts.

Another advantage is the absence of smoke and dangerous gases caused by the burning of fuse. A large percentage of these gases is carbon monoxide, as is shown by the following analysis of gases obtained from burning fuse.*

ANALYSIS OF GASES PRODUCED BY BURNING OF FUSE

(A. L. Hyde, Analyst)

Hydrogen sulphide	0.8
Carbon dioxide	32.7
Oxygen	1.4
Carbon monoxide	23.4
Hydrocarbons	4.1
Nitrogen	23.8
Hydrogen	13.8
	100.0

STORING

The place used for the storage of explosives should be substantially constructed, well ventilated, protected as much as possible from fire or lightning, and should be kept locked to prevent the entrance of children or irresponsible persons. At mines or quarries the ideal magazine is, of course, one of cement or of brick, but at most tunnels where the work is usually of a more or less temporary character, the cost of such a building is not always justified, and the dynamite is stored usually in a short drift in the side of the hill or in a log house. Where neither of these can be obtained, a frame house will answer the purpose, although of course not so well. But when it is used, it should always be covered with corrugated iron or some similar fireproof material, and care should be taken to remove any small sticks

* Bureau of Mines, Technical Paper 6.

and grass from immediately around it. Where considerable amounts are to be stored, the magazine should be located at some distance from the rest of the work, but in any case the powder should not be kept near enough to the tunnel buildings to cause serious damage to them or to the persons working in them in the event of an accidental explosion. Obviously, dynamite should not be stored at all near a dwelling.

More than one kind of explosive, as, for example, black blasting powder and dynamite, should not be stored together, but there is no particular objection to the storage of different grades of the same kind of dynamite in the same building, except the possibility of confusion which might result from such a practice. Detonators, either plain or electric, and fuse should under no circumstances be stored in the same building with dynamite, nor should the operation of placing caps on safety fuse be conducted at or near the magazine or thaw-house. Tools should never be permitted inside of the magazine, nor should the boxes of dynamite be opened there. The floor of the magazine should always be constructed of wood, and it should always be kept free from grit and dirt.

THAWING

Most dynamite freezes at a temperature of 45° to 50° F., and it is therefore necessary to thaw it before it can be used. In tunnel work this is generally accomplished by spreading it out on shelves in a warm room or small building, separate and preferably somewhat removed from the main magazine. Where the power for the tunnel work is derived from a steam plant, the waste steam is very often used to heat the thaw-house. In this case, however, it is very essential that the coils be boxed or screened in such a way that it will be impossible for a stick of dynamite to fall upon the pipe, for, becoming ignited from the heat, a serious explosion might result. Nor should the pipes be so placed that any nitroglycerine exuding from the cartridges can fall upon them. Since the thaw-houses are generally insulated from the cold by having double walls or by banking earth high against the sides (and hence a great deal of heat is not

required to keep them warm), where electricity is available, a cluster of incandescent bulbs is often used for this purpose with good results. At other tunnels a special heater was observed, which was composed of one or more coils of iron or other high-resistance wire stretched between insulators on a suitable framework, usually of wood. When a heater of this type is employed it is much more essential that it be protected from the danger of a stick of dynamite lodging upon the wires because they are generally much hotter than steam coils (a red glow being not uncommon), and hence there is much greater danger of explosion from this source.

At one of the tunnels visited, however, where otherwise the conditions from the viewpoint of safety were excellent, an unprotected heater of this type was employed, and when comment was made upon the fact that there was no protection, it was stated that this condition was intentional. The reason given for such a course was that any person entering the thaw-house was supposed to turn off the current by means of a switch provided for that purpose, and that the knowledge that the coil was not protected would make the men more careful in seeing that this was done. Such reasoning is all right as far as it goes, but it does not provide for the contingency of a stick of powder falling off the shelves when no one is in the building (although it is granted that this is not so likely to happen as the other); nor, since the wires do not cool off instantly, is it safe in the thaw-house for some little time even after the wires have been disconnected. Taken in connection with the fact that this particular thaw-house was but a short distance from the tunnel portal, that it had no lock, and that all timber and other tunnel supplies had to be hauled past it, the situation should have been marked, in the language of insurance, "extra hazardous." It is, indeed, truly marvelous that it did not occasion some accident during the period of its use. Needless to remark, such a thaw-house and means of heating it are decidedly to be avoided.

CHAPTER XIII

METHODS OF MUCKING

NUMBER OF MEN

The number of men in the crew which removes the rock broken in blasting exerts a very important influence upon the speed at which the tunnel can be advanced. Where the vertical column or the drill carriage is employed and the remainder of the work cannot proceed until the heading is cleared, every minute saved at this work can be transmuted directly into progress; and while, with the horizontal-bar system, nearly all of the mucking is done simultaneously with the drilling and the heading can ordinarily be cleared by the time the drillers have finished the upper round of holes, still if the crew of shovelers is not large enough to accomplish this promptly, the delay is fully as serious. In any event, it is very essential for rapid progress that the muck be removed as speedily as possible, as there are always a great number of little things to be done by the shovelers, even after the main work of loading the débris has been accomplished, for which there cannot be too much reserve time. Further, it is obvious that the removal of the muck in the shortest space can be accomplished only by a nice adjustment to conditions and the employment of the exact number of laborers proper for the purpose; for it must be remembered that the space in the tunnel heading is most restricted, and if too many men attempt to work there simultaneously, they will seriously interfere with one another, more than offsetting any possible gain from the employment of the extra men, while if too few men are at work it will be impossible for them to remove the débris in the time allowable. An analysis of the most satisfactory practice at a number of tunnels shows that, under the conditions which prevail in the heading, a man shoveling requires from two and a half to three feet of floor space. That is, for a tunnel ten feet wide, not more than four shovelers should be used

simultaneously, while not more than two men can work to advantage side by side in a six-foot heading. In addition to these, however, it is very desirable to have a man or two at work picking down the rock pile in front of the shovelers, loosening boulders, assisting in the handling of the cars, or doing any of the many other things that make for speed in loading the muck. Accordingly, at tunnels from six to ten feet in width, the proper number of men in the mucking crew ranges from three to eight.

At the Loetschberg and other of the European tunnels two sets of muckers were employed, one of which would rest while the other was engaged in loading the car. This course was thought to be conducive to greater speed, because the men could work much harder for the few minutes it took to load a car if they had an equal time to rest during the loading of the next one. There is but little if any doubt that this is true or that the heading can be cleared sooner when such a method is used, but because of the higher cost of labor in this country, especially in the Western States, it is greatly to be questioned whether the gain would be sufficient to make such procedure profitable. At the Loetschberg tunnel the shovelers received a daily wage of 80 cents * as compared with the $3 or $3.50 for like work in the western part of the United States, so that a double crew of but five shovelers (similar to those of the Loetschberg tunnel) would entail in this country an extra cost of from $15 to $17.50 per shift, as compared with $4 in Europe. Since the advance per shift in America rarely exceeds 7.5 feet, the extra cost of the double-crew system would amount to at least $2 per foot of tunnel driven. This would be justified only if it obviated a corresponding burden of delay, although even in that event the question could properly be raised whether a change or adjustment in some other phase of the work was not the better solution and desideratum.

POSITIONS OF WORKING

The advantage of giving the men a rest from the grind of steady shoveling can be obtained, however, without the necessity

* Saunders, W. L.: Bull. A. I. M. E., July, 1911, p. 532.

of extra laborers, by changing their positions regularly, according to the system in use at several of the tunnels visited while securing the material for this book. At the Laramie-Poudre tunnel, where one of the best examples of this method was observed, the six muckers worked according to the following cycle of operations: As soon as a car (1) was filled with waste, two shovelers, who will be designated as A and B, took it at once to the rear, while two other shovelers, C and D, jumped to an empty car (2) near by (which had previously been thrown off the track on its side), set it upright on the track, and pushed it into a position to be filled. In the mean time, the remaining men, E and F, stopped picking down the rock pile, took the shovels left by A and B, and started at once to assist C and D in filling car 2. Another car (3) was then brought up by A and B as near as possible to the car (2) being filled, and thrown off the track on its side in the position formerly occupied by the second car. These men then picked down the rock pile for the other four during the remainder of the time consumed in loading car 2. When filled, this car was removed by C and D, while E and F set up the third car and filled it with the assistance of A and B. The fourth empty car was meanwhile brought up by C and D, who then took their turn at picking down, and the cycle was completed when E and F took the third loaded car to the rear, returning with another empty and then resumed their original position on the muck pile. It will be seen that by this method every man spent at least one-third of the time in tramming or picking down the rock pile, either of which was easier work than that of shoveling and amounted virtually to a rest which, although perhaps not so complete as if no work at all had been done during that period, was still sufficient to relieve greatly the hard monotony of shoveling.

The regularity and mechanical exactness of procedure with this system are still more important advantages. Each man soon learns precisely what is expected of him for each step of the operation, and hence there is absolutely no confusion, no lost motion. There is rarely any occasion for the foreman to give an order to the men except under unusual circumstances, and in

consequence he does not acquire the habit of shouting at the men constantly, an unfortunate phase of this work only too noticeable at some of the tunnels visited; nor, on the other hand, do they form the time-wasteful habit of running to him for guidance at every minor contingency that arises. The statement that the little things make for success is not claimed as original, but it can nowhere apply better than in planning the utmost work attainable in the limited space of a tunnel heading; indeed, this seeming detail of eliminated friction and confusion warrants and deserves the most serious consideration.

In addition to advantages in organization, the speed attainable with this method leaves little, if indeed anything, to be desired. Cars of 16 cubic feet capacity were filled at the Laramie-Poudre tunnel ordinarily in three or four minutes, and on one occasion (which, however, was somewhat exceptional, as the men realized that they were being timed) but one minute and thirty seconds were needed. At the Rawley tunnel, where a similar system was used with but four muckers, twenty-five cars having a capacity of 17 cubic feet were filled in exactly two hours, and on a different shift twenty cars were loaded in one hour and forty-five minutes. These figures are from an accurately timed record kept by one of the authors. The usual time required for mucking at the Rawley tunnel is not far from the average of these figures (which also include all ordinary delay incident to making the cars up into trains), a value somewhat less than six minutes per cubic yard of rock loaded. This does not suffer by comparison with the Loetschberg tunnel, where five minutes were required to fill a cubic-meter car (35.5 cubic feet) * by a crew of *ten* men, with an extra minute to remove it when full and replace it with an empty one.

HANDLING CARS

The method of handling the tunnel cars is still another detail of consequence in the operation of mucking. One of the most common arrangements is to have them trammed from the face

* Saunders, W. L.: Bull. A. I. M. E., July, 1911, p. 535.

by hand to a siding or switch where they are made up into trains and hauled to the portal by whatever means are provided for that purpose. This system, however, possesses some disadvantages. The switch must be moved frequently at no little expense and trouble in order to keep pace with the tunnel advance or else it will soon be so far from the face that it is practically worthless. There is considerable loss of time while the loaded cars are being removed and the empty ones are being brought to the face, which it is impossible to avoid; even though every effort be made to reduce this time to the minimum, the switch cannot well be located nearer than 100 feet from the face, while in practice 300 to 500 feet is more apt to be the actual distance. Moreover, the full car must be taken usually by hand the entire distance to the switch before the "empty" can pass it; when this system is employed, heavy cars, almost without exception, are used (for reasons we shall show later), and, on this account, to move them any distance by hand entails a heavy drain upon the exertions of the mucking crew.

At some tunnels this difficulty was obviated by extending two tracks all the way to the face and loading cars on each one alternately. Even this is not entirely satisfactory, because it requires the extra labor and trouble of laying two tracks instead of one, which must be done after the tunnel is cleared of débris and before the new round is fired, and is therefore very apt to cause a serious delay in the whole work, especially if the shovelers are a little late in clearing the heading. In addition, the need for keeping the switch as close as possible to the face is not so apparent with this method as with the first, and hence this most necessary work is apt to be neglected. In that event a large amount of time will be wasted in the course of a shift by the men tramming the cars an extra distance. And, of course, it only partially obviates the danger of derailments to the cars in crossing the switches, which is often a notable cause of lost time and trouble.

At one tunnel the necessity for a double track was avoided by covering the entire floor of the heading with steel plates for about thirty or forty feet back from the face. The cars to be

loaded could easily be jumped from the track on to the first of these plates and rolled as near the rock pile as necessary, and when one car was full an empty one could be shunted around it without difficulty and placed in position for loading while the full one was being rolled back upon the track and trammed to the siding when the trains were made up. Such a method is simple and effective, and except for the work of moving the siding ahead requires but little extra labor; most of the plates are needed in any event for the men to shovel from, so that the work of adding one or two more would scarcely be noticed. This procedure is recommended where for some reason it is necessary to employ cars of large capacity.

But in most cases, as was pointed out in the section on haulage equipment (see page 163), it is much better to use cars of smaller capacity; then the empty ones are tipped off the track to allow the full ones to pass and can be righted when needed and placed back easily by two men, thus avoiding all the complications and extra work arising from the use of a siding or switch. The smaller cars are also easier to load, for since they do not occupy so much space in the tunnel heading there is more room for the shovelers to work; also, the sides of the smaller cars being lower, each shovelful of rock does not have to be lifted so high in order to get it into the car, saving both time and energy. They are likewise easier to handle in case of a derailment, and since fewer men are required for tramming them out of the heading when full, a larger percentage of the time of the shoveling crew can be spent in the actual process of loading.

When the smaller cars are used, however, the work of handling them must be thoroughly systematized in order to prevent waste of time through avoidable delays. Although similar to that in use at a number of the tunnels examined, the system employed at the Rawley tunnel was perhaps more carefully worked out in all the details than were any of the others. Upon arrival at the heading, the empty cars were pulled as near as possible to the full cars waiting to be removed, which at this juncture ordinarily stood on the track some 75 or 100 feet from the face of the tunnel. The mule was then detached from the empty

"trip" and used to pull the full cars back to the one being loaded, usually the last one of the previous empty trip; or if they had all been loaded the full cars were pulled back as near the face as possible. The empty cars were then hauled up to the full ones and tipped off the track on their sides out of the way. All of this work was performed by the mule-driver alone, except when the shovelers had completed the loading of the empty cars, in which case they assisted wherever possible in order to expedite matters. After seeing that the cars of the full trip were properly coupled up, the driver then started with them for the dump and the muckers took the two empty cars nearest the portal, set them on the track, and trammed them to the face where one car was again tipped off on its side while the other was being loaded. Unless the mule-driver was delayed in getting to the heading so that he did not arrive before all of the cars of the previous trip were filled (an event not of frequent occurrence, however), the operation of getting the loaded trip out of the heading and an empty car again in position to be loaded, rarely occupied more than from three to five minutes. The remainder of the cycle was similar to that just described for the Laramie-Poudre tunnel, each full car being trammed a short distance beyond the last one of the empty trip, which was then taken up to the face and thrown on its side ready for use without delay when needed.

To recapitulate, then, the chief advantages of this system are: (1) it does away with a switch near the heading; (2) the cars do not have to be trammed any great distance by hand—only a little more than the length of one trip—and the distance is constant and does not vary with the tunnel advance; (3) the minimum time is consumed in getting the full car out of the way and replacing it with an empty one, and (4) very little time is lost in making up the trains to be hauled to the dump. It cannot of course be used satisfactorily unless the cars are small enough to be handled easily by two men, but this is a matter which can be provided for in purchasing the equipment and, as has been shown, the smaller car has other advantages which make it very desirable for tunnel work. A

system similar to the one outlined, modified of course to fit local conditions, is highly recommended for future tunnel work.

USE OF STEEL PLATES

The use of steel floor plates from which to shovel rock broken by the blast has become so general that mention of this feature of mucking should hardly be necessary. The authors were much surprised, however, to find at one or two tunnels, where otherwise there was little left to be desired in the line of organization and equipment, that the muck was being shoveled without the use of plates. Even the most cursory study of this work, noting the efforts of the men in pushing the shovels into the rock-pile along the uneven surface of the bottom of the tunnel and comparing the time required to load a car with the results at other tunnels where steel sheets were in use, soon made it evident that large quantities of both energy and time were being wasted needlessly.

At one tunnel the plates were not used because it was necessary to excavate the floor on a curve instead of making it flat, as is usually the case, though even here plates could have been employed by leaving a portion of the waste material in the bottom of the tunnel to form a flat surface upon which the sheets might have been placed. Upon inquiry at another tunnel the following reasons were given for their non-use: (1) The muck was so sticky that it would not be at all easier to shovel from the plates than from the rock-pile; (2) it was impossible to prevent the sheets from becoming bent, twisted, and jumbled up with the muck when the holes in the bench were blasted; and, (3) it was a great deal of trouble to lay them in position before blasting and to handle them during the work of mucking.

Now, while it should be admitted in all candor that the stickiness of the muck in this instance made it difficult to handle under any conditions, there is no good reason to suppose that shoveling from a plate would have been more arduous than from the pile—quite the reverse. The second objection is somewhat more serious; for it is true, especially with heavy blasts, that the sheets are sometimes caught up and twisted by the explo-

sion and occasionally hurled for considerable distances down the tunnel. Where the plates are properly covered with waste rock from the previous round before blasting, however, such occurrences are so extremely rare as to be negligible, and this is ordinarily the remedy for such difficulty. But at the particular tunnel under discussion the trouble was somewhat different. It was being driven with a heading nearly square, and this was followed at a distance of eight to ten feet by a bench three to four feet high. The holes in the bench were drilled from the same set-up as those in the heading, and they "looked" down and away from the heading and hence toward and slightly under the position that would have been occupied by the steel sheets. It is not surprising that with this arrangement a great amount of difficulty should have been experienced in keeping the plates down during the short time they were tried. The objection in this instance should not have been taken to the steel sheets, but to the design of the tunnel itself, which was being driven considerably higher than it was wide, but would have served every purpose required of it equally well if the dimensions had been reversed. Such a change would not only have obviated the sheet trouble, but would also have made it easier to drive in other respects. Aside from this, the tunnel was not high enough to warrant the removal of the material in two operations, as was being done at the time it was visited. Since then, however, the bench was abandoned, all of the material being excavated at once, which made it possible for the mucking to be done without difficulty from steel plates.

The third criticism is entirely a question of economy and can best be met by inquiring whether it is not better for the muckers to spend fifteen or twenty minutes while the drillers are loading the holes, and possibly as much more time during the mucking, in doing work that will save itself several times over. For it cannot be denied, and has been proved time and again, that a man can work to much better advantage and handle more rock during a given time if he shovels from a smooth surface. And this is only what is to be expected when one realizes that in so doing he encounters but very little resistance other than friction in

pushing the shovel home, and is therefore able to secure a shovelful with the minimum expenditure of energy and in the shortest time. But when shoveling from the pile, the shovel can rarely be pushed more than an inch or two without encountering a piece of rock too big to be shoved aside (although the effort is usually made to do so), and there must, therefore, be a distinct stop while the shovel, with any load upon it, is lifted clear of the obstruction, only, in all probability, to encounter another one almost immediately. It is not surprising, therefore, to find that the experience at a large majority of tunnels leads to the conclusion that steel plates for shoveling are among the chief economies.

CHAPTER XIV

TIMBERING

MATERIALS

When the rock through which a tunnel is driven does not possess sufficient strength and rigidity to carry the weight of the superincumbent mass, artificial supports for the roof, sides, and sometimes for the bottom are necessary to prevent the rock from falling, crumbling, or squeezing into the excavation. These supports may be timber, brick, stone, metal, or concrete. Because of its cheapness and availability in many mining districts, and the ease with which it can be cut to the required sizes and shapes and placed in position, the first of these is the one most generally employed; and even where masonry or concrete lining is called for in the specifications of the completed tunnel, timber is almost always used as a temporary support until the more permanent material can take its place.

In most underground situations seasoned timber is preferable to green because it is better able to resist decay; and the bark should invariably be removed from round logs, as the space between it and the wood affords an excellent breeding-place for many forms of wood-destroying insects, while the bark itself collects moisture and thus encourages the growth of fungi which are the chief wood-destroying agents. Round timbers when properly peeled and seasoned are more durable than square timbers cut from a similar log of the same size and age, because the corners of the latter are especially liable to decay. In young and small timber, such as is generally used for mining work, the outer half of the log is usually sapwood containing starch, sugars, proteids, and other soluble organic compounds, the foods upon which decay-producing fungi thrive, and which are practically wanting in the heart wood. In the process of squaring up, where, as is usually the case, the attempt is made to secure the largest possible square timber from a given log, the corners

consist largely of this easily infected sap-wood and are accordingly most liable to conditions bringing about quick rotting. It is not surprising, therefore, to find in moist underground workings where square timbers have been in place for three or four years that the corners of the timbers have decayed to such an extent that they can be pried off down to the heart wood with a miner's candlestick or any other sharp instrument. It is, of course, true that the outer portion of a round log also consists of sap-wood, but the exposed surface has not been injured or bruised by the saw.

While round timbers deteriorate much more slowly than square, they are not so easily handled in the tunnel, and they are also harder to align properly; it is also much more difficult to reinforce them by the ordinary false sets or pieces. Where timber must be transported long distances the greater weight of the round sticks (especially where the logs are truncated cones—or "churn-shaped," as the miners say—instead of being nearly cylindrical), the freight costs become prohibitive and square timbers must be used. Under these conditions the saving in transportation charges will often pay for some type of preservative treatment to be applied to the timbers before being placed underground.

The best method of checking the growth of fungi, and by so doing increasing the durability of timber, is to poison the source of their food supply, and although there have been many processes invented for this purpose, most of those in use to-day depend upon the injection of either zinc chloride or creosote. The former cannot be used advantageously in wet situations, however; for since it is soluble in water it would soon be leached out, leaving the timber just as susceptible to attack as before. But when creosote has been properly applied it cannot be washed out, no matter how much water passes over the timber, and for this reason it is the preservative generally employed in mining and tunnel work. It is, however, somewhat more costly than the former, and since it is a liquid, the transportation charges are considerably higher, while the zinc chloride can be shipped in bulk.

Creosote can be applied as a surface coating by painting with a brush or simple immersion in a tank, or the log can be more deeply impregnated with the preservative by one of the more complicated processes involving heat, pressure, or vacuum. Although painting is the least efficient method, it has the advantage of cheapness, and if carefully done will give fairly satisfactory results. While dipping or simple immersion results in but little if any greater penetration of the preservative, it insures a more certain filling and coating of the cracks, checks, and other imperfections of the log and thereby affords better immunity from decay. It is also in most cases cheaper than painting because it is more economical of labor, it being easier to run a number of sets of timber through a vat on some form of mechanical conveyer than to paint the same number by hand. For either method the timber must be fully dried and seasoned beforehand, otherwise cracks in the wood due to the evaporation of the moisture will break the protective covering, which is only a thin one at best, and thus give the fungi access to the interior of the stick. It is perhaps unnecessary to add that these, as well as any of the other treatments, should not be given the timbers until after they have been cut to form, so that the ends and the mortise openings may be coated as well as the sides.

Where the extra cost of a more thorough impregnation is warranted, the "Bethell" process is widely employed for timbers that are to be placed in wet situations. By this treatment the timber is for several hours given a bath of live steam at perhaps twenty pounds pressure, after which it is subjected to a vacuum for three or four hours more, when creosote, heated to a temperature of approximately 160° F., is applied under pressure until the desired amount of the preservative is forced into the wood. "Burnettizing" is a process practically identical with this, except that zinc chloride is used in place of creosote. There are also a number of methods less frequently employed which are designed to effect economy in the amount of chemical required, and which differ chiefly in the manner of its application. In one or two of them the interior of the timber is impregnated with the less expensive zinc chloride which is in turn protected

from the action of water by treating the outer zone with creosote. A more complete discussion of processes than can well be included in this book may be found in Forest Service Bulletins 78, "Wood Preservation in the United States," and 107, "The Preservation of Mine Timbers."

For permanent tunnel linings, brick and stone were formerly the chief materials employed and most of the older tunnels both in this country and abroad are lined in this manner. Such linings are expensive, however, and require a higher class of labor to place them in position than does concrete, their modern substitute, nor do they afford the same imperviousness. Although metal beams and posts are sometimes employed advantageously as roof supports in the main entries and gangways of coal mines, high cost prevents their use except for this or work of similar importance. The best modern material for permanent linings is undoubtedly concrete; and although its employment in this work has thus far been restricted chiefly to railroad, irrigation, or water-supply tunnels, its use in practically every important mining tunnel where a permanent lining is necessary must almost certainly follow.

TYPES*

The simplest forms of roof support are of course a post, or single timber supported by a "hitch" or recess in the side wall. Where the sides of the tunnel are not strong enough to afford a hitch, the ends of the cap are supported by posts; and if the floor will not bear the weight of the posts, a sill is placed for them to rest upon. Figure 65 illustrates such a four-piece set applied to as small a tunnel as it is usually advisable to excavate.

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* As tunnels and adits for the purpose covered by this book are rarely too large to be driven as a single heading, the many complicated and ingenious systems of timbering which are used in driving large railway tunnels, either with multiple headings or single heading and bench work, need not be considered here. For a discussion of these methods the reader is referred to the monumental work of Drinker ("Tunneling, Explosive Compounds, and Rock Drills," Drinker, Henry S., New York, Wiley & Sons); to Prelini ("Tunneling," Prelini, Charles, New York, Van Nostrand); Stauffer ("Modern Tunnel Practice," Stauffer, David McNeely, New York, *Engineering News*), and the publications of the Civil and Mining Engineering Societies.

The timbers are 8 inches by 8 inches, and instead of partially beveling them to withstand side pressure the posts are held apart by a 2-inch by 8-inch plank spiked to the cap. Figure 66

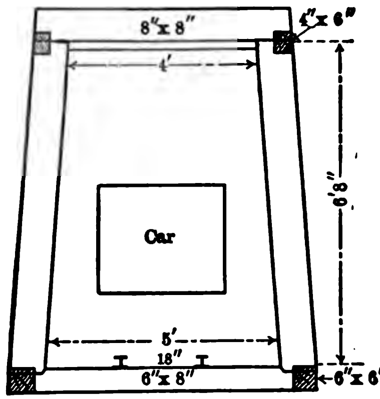

FIG. 65. Four-piece set of timbers for a small tunnel.

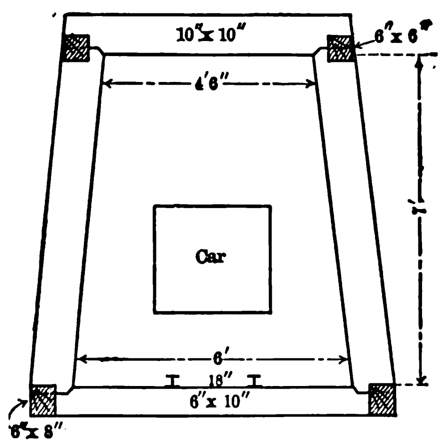

FIG. 66. Four-piece set for a tunnel of a convenient size.

illustrates a very common form of timbering designed for a tunnel of a convenient size for driving where a single track is all that is required. The timbers are 10 inches by 10 inches and the joint between the cap and the posts is beveled at the corners

so that the timbers can easily resist horizontal or vertical pressure without splitting. If heavier ground is encountered than can be held with this set, the posts and cap can be made of 12-inch by

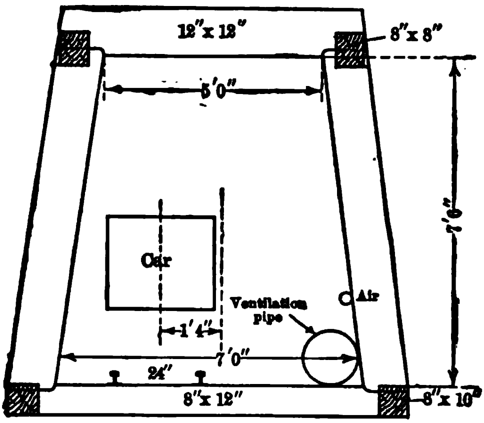

FIG. 67. Arrangement of timbering providing a manway at one side of the tunnel

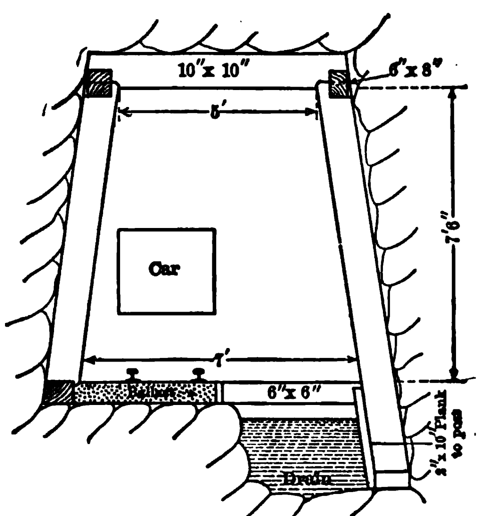

FIG. 68. Timbering for a wet tunnel.

12-inch timbers, with 8-inch by 12-inch sills, and 8-inch by 8-inch collar "braces," as they are commonly called.

In single-track tunnels where there is considerable traffic, it is often advisable to have the opening wide enough to give room for a manway and the ventilating pipe on one side and the car tracks on the other, as shown in Figure 67. Or if the tunnel has to carry a considerable volume of water, the design shown in

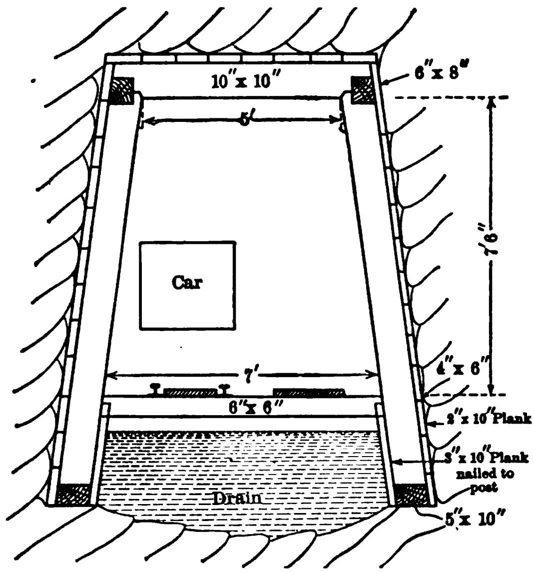

FIG. 69. Timbering for a tunnel producing a large volume of water.

Figure 68 has been used in many instances and has given excellent satisfaction, notwithstanding the fact that both the opening and the timbers are unsymmetrical. The 6-inch by 6-inch sill, which also forms the rail tie, is not notched into the post on the right side, but is merely held in place by a 2-inch by 10-inch plank spiked to the face of the post, the upper end of the plank being recessed for a depth of 4 inches to receive the sill. Where even larger volumes of water have to be provided for, the arrangement illustrated in Figure 69 has given very good results at a number of places where it has been tried. The amount of water and the grade of the tunnel, of course, determine the proper

depth of the drain. The sill is supported by planks spiked to the posts, as in the preceding case.

Where the roof pressure becomes too great to be carried by a horizontal cap, what is known as the "arch set" is usually employed. Figure 70 shows the design of such a set for a tunnel

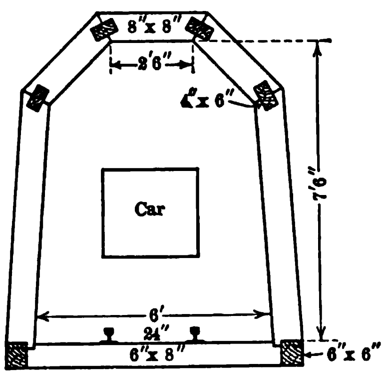

FIG. 70. Arch set for a small tunnel.

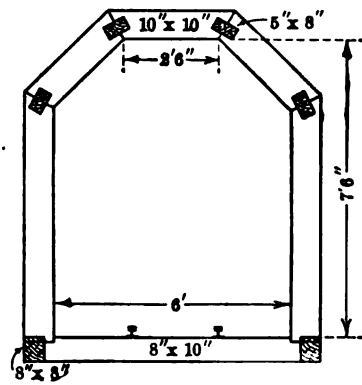

FIG. 71. Arch set with vertical posts.

7 feet 6 inches high by 6 feet wide on the sills. The timbers are 8 inches square and the collar braces 4 inches by 6 inches. Instead of placing the braces on the outer edges of the timbers, as is done on square sets where they can be slipped in from the outside, the collar braces on arch sets should be mortised into the face of the timbers in a central position, bisected by the joint, as shown in the illustration. By this means the bevel pieces forming the arch, being much more difficult to hold in place while being blocked than are square sets, are prevented by the braces from slipping. If more room is required in the upper portion of the tunnel than is given in this design, vertical posts are often used (see Figure 71), a substitution which not only increases the width of the tunnel at the shoulders but calls for all timber cuts at an angle of 30°, making the sides and the top pieces of the arch interchangeable. Figure 72 illustrates the arch system of timbering as employed in medium heavy ground for a tunnel 8 feet in width by 7 feet 6 inches in height, which is

about the minimum size for a double-track tunnel. If the walls of a tunnel are sufficiently firm to stand without timbers and only the roof requires support, the arrangement shown in Figure 73 can often be used to advantage. This system makes a care-

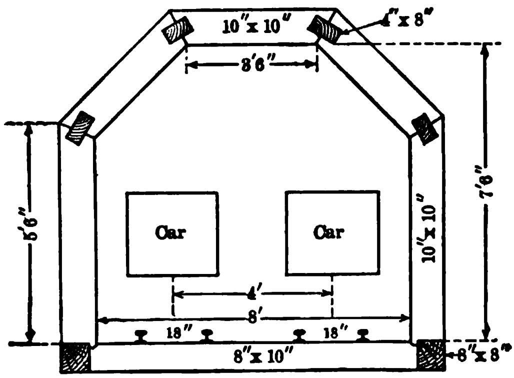

FIG. 72. Arch set for a double-track tunnel.

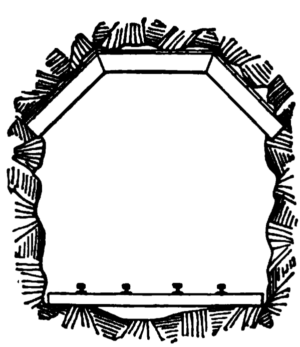

FIG. 73. Arch roof support and hitch.

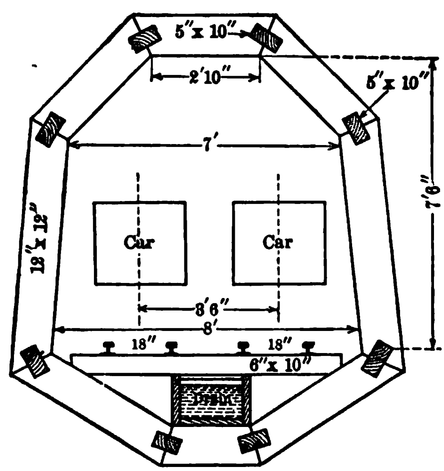

FIG. 74. Inverted arch set for swelling ground.

fully constructed footing for the arch timbers necessary, but hitch-cutting with a modern hand pneumatic drill is comparatively a cheap operation, the cost of which will be repaid many

times by the saving in timbers and in the smaller amount of rock to be excavated.

Swelling or creeping ground results from the exposure of certain rocks to the air, whereby they undergo chemical change and increase in volume so that the excavation not only closes in from the sides and roof but swells up from the floor as well. Under such conditions it is sometimes necessary to design the timbers as shown in Figure 74, where the drain box and the track are protected by an inverted arch. Where 12-inch by 12-inch timbers in this form will not resist the squeeze at the usual distance of 4 feet between centers it is customary to close them up until they have sufficient resistance to withstand the pressure. Occasionally, however, zones of rock are encountered that cannot be held even by this expedient, in which case the timbers can be kept from breaking by placing the sets about 3 or 4 inches apart; then, whenever the pressure becomes too

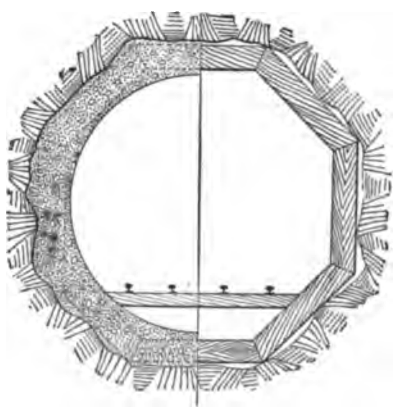

FIG. 75. Octagonal set of tunnel timbers.

great, it can be reduced by removing with a long-bladed pick whatever decomposed rock is in line with the open spaces, 4 or 5 inches back from the timbers. Swelling ground is usually so soft that this can be done without much trouble, and it is neither a difficult nor an expensive matter to keep a wood-lined tunnel open until it can be lined conveniently with concrete, which, by preventing access of air to the rock, will remove

much of the difficulty. The octagonal set (see Figure 75) offers another means of holding such heavy ground, and it is often advisable to follow it up with concrete in front of and between the timbers as shown on the left side of the illustration. To insure the safety of the tunnel after the timbers have decayed, the sets should not be spaced less than 12 inches apart, while 15 to 18

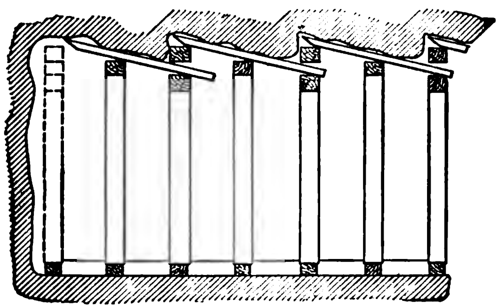

FIG. 76. Timbering for loose ground.

inches is still safer, since the wider opening gives room for a stronger rib of concrete between the timbers. The above is an exceedingly easy section to handle, and, where the flow of water is not too great for the drainage area underneath, nothing better could be adopted. All the pieces in this timber set are exact duplicates, and this is a great convenience not only in framing, but also in storage and erection.

An entirely different problem from swelling ground, and one temporarily much more difficult to handle, is often encountered where adits or tunnels have to be driven through shear zones, caved ground, or loose crushed material which will not stand overhead without being supported as fast as it is opened. One of the oldest designs for driving through areas of this description is shown in Figure 76, where each alternate set carries a double cap. This arrangement is simple, easily operated, and very satisfactory where the material in the roof or sides does not bring too much pressure on the spiling.* The method possesses,

* Where the lining of a tunnel can easily be placed in position it is usually known as lagging, but where it has to be sharpened to a chisel-shaped end and driven into position it is called spiling or forepoling.

however, two grave disadvantages: it requires two different sets of timbers, and the spiling used must be long enough to cover both sets. This latter difficulty, where the overhead material is heavy, sometimes proves serious, as it is often difficult to drive spiling across one space, to say nothing of two.

Under such conditions, the tail-block system, illustrated in Figure 77, is generally employed. Since the timber sets are all

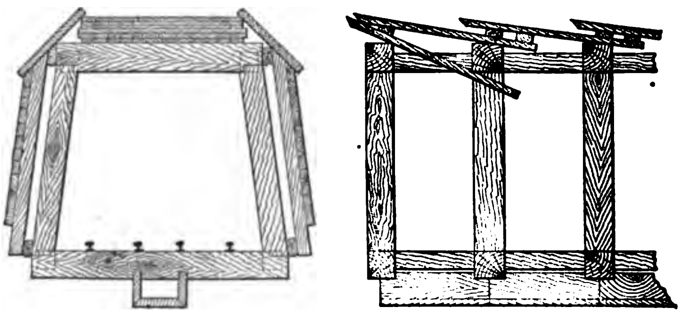

FIG. 77. Tail-block system of timbering.

the same size, it avoids one disadvantage of the preceding case, nor do the sets differ in any particular from those used with ordinary lagging. It offers, however, but little improvement in the matter of driving the spiling in place. To be sure, the spiling does not have to cover two sets, but where the ground is heavy the great pressure brought upon the tail-block by a comparatively small amount of rock resting over the spiling as it is being driven forward creates an amount of friction which, added to the resistance in front of the spile, makes driving exceedingly difficult even with the heaviest sledges that can be used. Even if the greatest care be taken, the back end of the spile is often broomed and split by the heavy pounding required. This can be obviated in part by capping the back end of the spile with an iron shoe, and a heavy piston drill is sometimes employed to do the pounding. Where the ground over the tunnel is very much shattered and weak, making the continued hammering on the spiling dangerous, it is safer to force the spiling slowly forward with light jack screws, and thus avoid the jarring effect of sledges.

When an opening has to be driven for any considerable distance through soft material requiring immediate support, the work can be expedited greatly by the use of what is known throughout the West as the swinging false-set, illustrated in Figure 78. Like many other inventions, this system was the child of necessity and was first used in the Cowenhoven tunnel, at Aspen, Colorado, where the overlying rock brought so much pressure on the spiles that it was almost impossible to drive

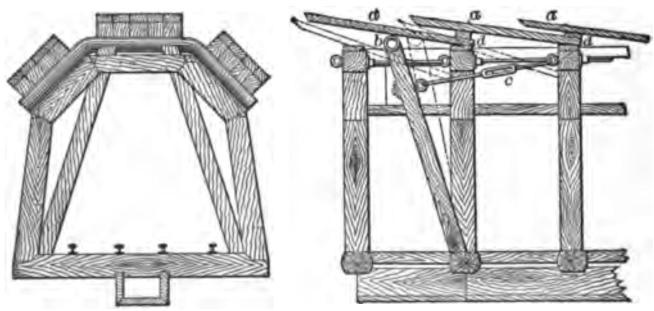

FIG. 78. Swinging false-set for loose ground.

them forward with an eighteen-pound sledge. With this method no tail-blocks are employed, nor need the spiling be driven across two sets of timbers as in Figure 76. The weight on the front end of the spiling is carried directly on the swinging false-set, and the spiling can be driven into place with a quarter of the hammering necessary under the tail-block system. As will be seen by inspection of the longitudinal section, the posts of the swinging false-set rest and rotate on the sill of the permanent set and when first erected occupy the position shown by the dotted lines. They carry a circular steel cap *b*, which supports the front end of the spile *a*, so that the only pressure to be overcome in driving is that of the rock immediately above and in front of the spile, and it is consequently much easier to drive it forward than in the tail-block system, where a weight of 100 pounds on the front of the spile would easily cause a pressure of five times that amount on its supports. As the spiling is driven forward the turn-buckle *c* is slowly unscrewed, allowing the

swinging false-set to fall forward and carry the point of the spiling in a nearly horizontal line. When all of the spiles have been driven home and the supporting block *d* is placed under them, the turn-buckle *c* is unscrewed still further, permitting the hanging rods to be unhooked from the eye-bolts and the false-set advanced to a new position, one set farther ahead. The system requires that the timbers for at least five or six sets from the face shall be bolted together in very much the same manner as hanging-bolts are used in placing shaft timbers; this, however, is a direct advantage rather than the reverse, for by bolting the timbers together and screwing them tight against the braces, they can be placed in position much more easily and quickly. Further, the timbers are held together so firmly that if hard ground is encountered in any part of the face, much heavier charges of explosives can be used than if they were held in place merely with blocks and wedges. The swinging false-set works equally well with square or arched sets, but where the latter are used the collar braces should be shifted from their normal position on the center line of the timbers, as shown in Figures 70, 71, 72, and 74, to the outer end of the joints to make room for the greatest possible width of spiling; by this means the angle gap can be reduced to a minimum and the length of the "lacing," correspondingly reduced.

In driving a heading where the character of the rock necessitates timbering close to the face, care must be taken thoroughly to brace and block the front sets before firing. Where the roof "breaks high" and there is any possibility of large masses dropping out of it, the space between the lagging and roof must be completely filled either with waste or blocking, otherwise a large piece of rock may drop from the roof and pass completely through the lagging, and thus endanger the lives of the men below. Timbering close to the face always diminishes the rate of progress by compelling the use of shallower holes and lighter charges. An excellent plan to permit of heavier rounds under these conditions is to keep the last six or eight sets of timbers firm and tight up against their collar braces by the use of tie bolts. These should be provided with center hooks to

permit of their ready removal, on the same plan as the hanging bolts which have so long been successfully used in shaft sinking. Only six or eight sets of bolts are required, those from the rear being moved forward and used in the face. This system of tying the sets together has been found to be equally advantageous in horizontal and in vertical driving.

The tunnel shield, such as is generally employed with or without compressed air for piercing subaqueous river-bed deposits, affords another solution of the problem of driving through soft ground. While in the matter of speed, safety, and economy the modern shield leaves little to be desired, it has one great drawback—the initial cost of the installation—which practically bars it from use for the narrow zones or small areas of running ground usually encountered by the class of tunnels we are considering in this book.

The system of timbering employed at the north end of the Elizabeth Lake tunnel of the Los Angeles Aqueduct is of especial interest because of the ingenious and extremely effective means employed to drive through a comparatively hard rock which, however, was so shattered and broken that it could not be trusted to stand even temporarily without support; in addition, the speed and efficiency with which the timbering was placed in position were notable, enabling as they did the north end of the tunnel to progress practically as fast as the south, although in the latter but very little timbering was required. The following description is taken, with some condensation and re-arrangement, from an article by R. L. Herrick, in *Mines and Minerals* for October, 1910.

The main tunnel, which was approximately 12 by 12 feet, was preceded by a short pilot heading having dimensions of approximately 8 feet by 8 feet, in which the roof was supported by "false" timbering. Assuming for convenience the time of inspection to have been at the end of a shift with the drills removed from the breast preparatory to blasting the round, the position of the timbers would have been somewhat similar to that shown in Figure 79 (*a*), which represents a short timbered section of the full-sized tunnel and the horizontal timbers used

temporarily in supporting the roof of the pilot heading. The posts of the permanent sets were 8-inch by 8-inch square timbers, 8 feet 6 inches in length; and in the figure they are spaced longitudinally at eight-foot intervals, although in practice they were often set irregularly. depending upon the weight of the roof.

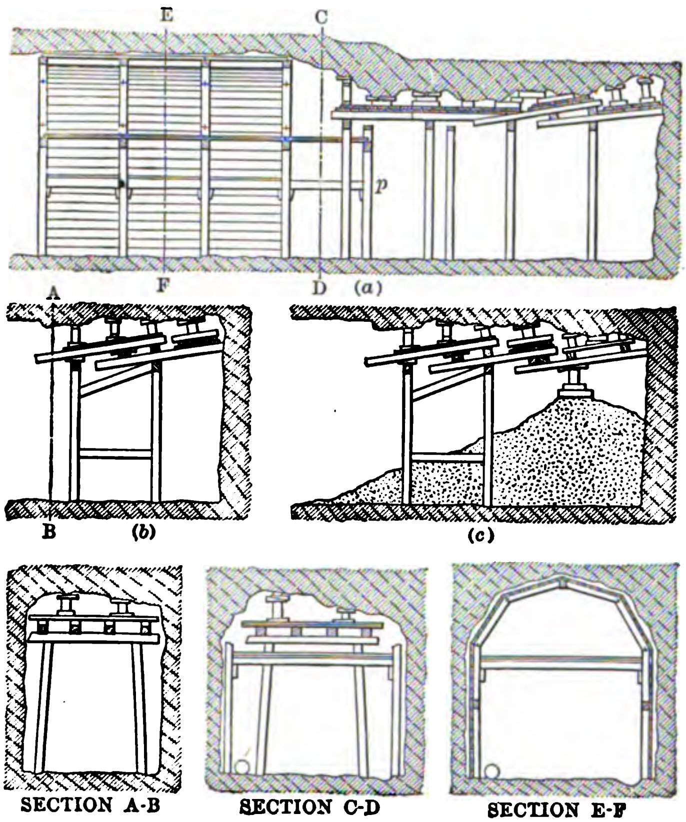

FIG. 79. System of timbering at Elizabeth Lake tunnel.

The width between the posts was 10 feet 2 inches in the clear, while the tunnel was broken as nearly as possible to a width of 12 feet. The collar braces were ordinarily 2-inch by 6-inch planks whose ends were supported either by wedges or timber-ends spiked to the set. The false posts in the heading were later used

as permanent posts for the full-sized tunnel, and as one end of them was beveled to carry pieces of the permanent arch, these beveled ends were placed next the floor in the heading, while their squared ends supported the temporary caps, which likewise consisted of timbers already cut to form and which were later used as permanent posts. In this way there was no handling of heavy timbers not intended for permanent use. Just before blasting, the false timbers were carefully braced and wedged to the roof as tightly as possible, as shown in Figure 79 (*b*).

As soon as possible after the blasting the timber-men went back to the heading to shore up the new roof temporarily from the top of the rock pile. For this purpose, two horizontal timbers, supported from the broken rock close to the side walls and having transverse timbers and blocking resting upon them as shown in Figure (*c*), were placed by the timber crew, an operation which interfered but little with the work of the muckers shoveling back from the face to allow the placing of the drills. The débris was next removed down to solid bottom to permit the setting of false posts which, when capped, then carried the weight of the roof.

Timbering the tunnel during the enlargement to full size was not a difficult operation. Starting at the last permanent set and proceeding toward the face, new permanent posts (shown in *a*, Figure 79) were placed in position as fast as the section was widened by picking down the side walls. Transverse spreader timbers, shown in section *CD*, Figure 79, were then placed between these posts with their bottoms 14 inches below the joint and resting on timber ends spiked to the posts. Across these spreaders were laid two tiers of two-inch plank, forming a floor 4 inches thick. This floor was some 2 or 3 inches below the bottoms of the caps resting on the false posts, so that it was easily laid while the false sets continued to hold the roof. Working from the end of this floor, the wedges and blocking transmitting the roof weight to the false set were next carefully knocked out and the shattered roof picked down on the floor, from which it was later dropped into cars. By placing the permanent posts a foot or so in advance of the false posts as in

a, Figure 79, the arch timbers of the permanent sets could be put in position as soon as the roof was sufficiently removed. Lagging and wedging quickly followed, so that the roof was supported by the permanent sets shortly after the removal of the false blocking.

Although lining a mining tunnel with concrete is not, strictly speaking, a type of timbering, both have the same function—that of supporting the roof and walls. In this work the concrete is usually placed in the openings between the timbers and for a few inches in front of them, which, where the sets are not spaced too closely together, is generally sufficient, even though later decay of the wood results in a corresponding weak spot in the lining. This defect can be avoided, however, by the use of posts and caps made of reinforced concrete in place of wood, a practice which has been recently introduced and which is finding great favor wherever its added expense is warranted. The concrete posts and caps are made outside of the tunnel in a mold which gives them the identical form of the wooden pieces they displace; and by proper reinforcement they can be made equal, if not superior, to timbers in strength, a strength which is practically permanent.

In water-supply tunnels a concrete lining performs the additional function of obviating eddies and friction against the otherwise irregular walls, and for this reason such tunnels are generally lined throughout, irrespective of the needs of the roof for support. On the Los Angeles Aqueduct the tunnel lining was generally at least 8 inches in thickness where the tunnel was not timbered, although an occasional rock projecting into the concrete was not removed unless it came within 4 inches of the inside finished surface of the lining. In timbered ground, concrete was placed between the timbers and for a minimum distance of 4 inches in front of them. The inverted siphons of the Catskill Aqueduct were lined with concrete which was ordinarily 2 feet thick, but solid rock was permitted to project without removal to within 10 inches of the interior surface. Owing to the great hydrostatic head, sometimes as high as 700 feet, to which these linings were to be subjected, every piece of timber

was removed before the concrete was put in place, and where it was necessary to support the roof during the time the concrete was setting, steel roof supports were designed and placed for this purpose.

At the Snake Creek tunnel (where a zone of swelling ground was encountered which resisted all efforts to hold it in the ordinary way, the strongest timbers that could be obtained being

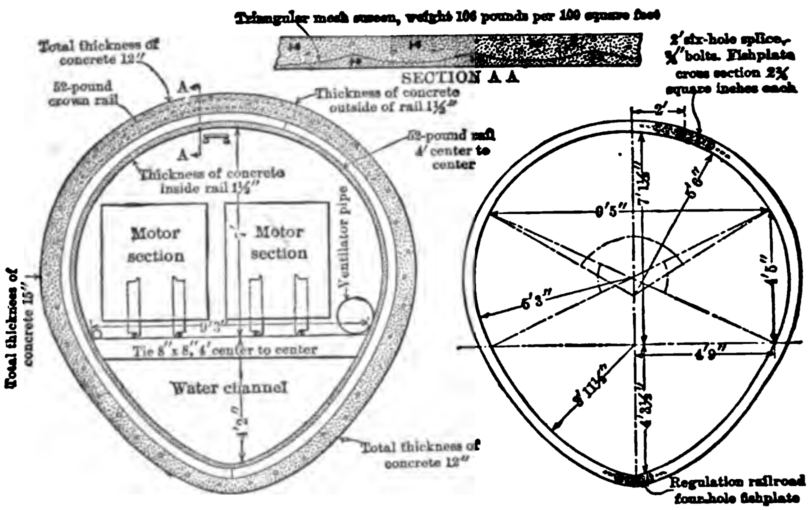

FIG. 80. Reinforced concrete lining at Snake Creek tunnel.

crushed and broken in less than a month's time) a concrete lining reinforced with steel rails was installed. The accompanying illustration of this lining is practically self-explanatory, but a complete description of it may be found in the *Engineering Record* for May 25, 1912. Where large volumes of water have to be carried through ground extremely difficult to hold, this design seems excellent, although its cost would be prohibitive for anything except important tunnels draining large areas of well-developed ground.

CHAPTER XV

SAFETY

DATA collected by the Bureau of Mines show that an average of nearly four men for each 1,000 employed in and about the metal mines of the United States were killed during the year 1911, as compared with 3.8 per 1,000 in coal mining during the same period. Although complete figures for accidents in tunnel driving cannot be obtained, a study of such data as it was possible to collect indicates that the number of deaths per year per thousand men employed has been somewhat greater than the above figures, the result obtained by averaging data extending over periods of from one to ten years for sixteen representative tunnels being 4.7 deaths per year per 1,000 men employed. In addition to the men killed outright, nearly four times as many more have been seriously injured, or perhaps maimed for life, and almost thirteen times as many slightly injured by accidents in tunnel work. By far the largest portion of these deaths and injuries were caused by falling ore or rock from the roof or walls of the tunnels, but the careless use of explosives, haulage, electricity, and other causes have each claimed their quota of casualties.

Are these accidents preventable? Not *entirely*, because there are some elements of danger impossible to eliminate and inherent in the work of driving tunnels; such, for example, as the danger from some unforeseen falls of roof, from the derailment of tunnel cars, or the certain risk when handling even the safest explosives by the most approved methods. But it is equally true that much of the present mortality and injury is the result of ignorance or gross carelessness, and can be avoided. When, for instance, a man sees fit to thaw frozen dynamite in a frying pan or by a candle flame, there is nothing accidental about the explosion which ensues, except, indeed, the fact that a man so ignorant or

reckless should have been entrusted with so dangerous a substance! Nor is the responsibility for accidents entirely on the part of the miner. The manager and his representatives are in many cases either ignorant of the precautions which should be taken for the safety of the men under them, or most negligent in seeing that they are properly and consistently carried out. The following paragraphs are written, therefore, in the hope that, by bringing these matters once more squarely to the attention of the men interested, much of the needless death and suffering may be prevented.

CAUSES OF ACCIDENTS

Falls of Roofs

There are many causes which combine to make falls of rock from the roof by far the greatest source of danger in tunnel work, but perhaps the chief of these is the common practice of greatly overloading the holes with explosives. Extremely heavy charges shatter and crack rock which would ordinarily stand without any danger of falling, and render it extremely dangerous to the men working underneath. Of course, it is essential to efficient work in tunnel driving that the blast should completely "break bottom" without any necessity for a second loading and firing; still every foreman and superintendent should see to it that the very smallest amount of dynamite that will do the required work is employed in the holes near the roof. Economy of explosive demands this, all other considerations aside; but the *dangers*, also, of the heavier charges should be thoroughly appreciated by the superintendent and, when such charges seem imperative, extra vigilance should be exercised and extra precautions taken along other lines for the safety of the men.

Another prolific source of accident is the fact that men will sometimes return to the tunnel face, after shooting a round, without thoroughly testing the new roof just exposed by the blast. It should be the duty of every man employed in the tunnel to examine the roof under which he must work, and especially in that part of the tunnel newly exposed after shoot-

ing; the foreman, upon reaching the heading after the blast, should at once detail one or two men (or as many as prove necessary) to clean down thoroughly all the loose pieces of overhead rock. Fortunately, this is done regularly at all well-organized tunnels, and it is a practice that cannot be too highly recommended for universal use.

It must be admitted that there are times when even experienced men believe the roof to be sound, when suddenly and without warning a large block crashes into the tunnel. This, if anything, will be claimed as a purely accidental occurrence, yet even the danger from such a rock (which may have been perfectly solid when first exposed, but had become loosened by the concussion of subsequent blasting) is, in many cases, overlooked because of the lack of illumination in which all tunnel work must be done, and might have been discovered in time if there had been a systematic and regular examination of the entire roof of the tunnel. As some one has pointedly observed, "The fall of a slab of rock weighing anything less than one ton should at once be charged to carelessness."

It should be said in this connection that the "sound" of the roof is not a proper criterion of its safety, since there are on record numerous cases in which the sound of the roof was satisfactory and showed apparently solid rock even to very experienced men, but in which a big block or boulder was actually loose. The better method of testing the roof—one used by many large mining companies and recommended by the Bureau of Mines—is to strike it with a pick or a heavy stick, at the same time touching the doubtful piece with the free hand. If any vibration is felt, the rock is unsafe and should be taken down or supported at once. If the roof is too high to reach with the hand, a stick should be held against the doubtful piece while it is being struck, and if it is loose the vibration can be felt through the stick.

Prompt and adequate timbering is extremely important. But timbering is a laborious process, and it either takes the men of the tunnel crew from their regular work or it requires extra men. Even in the latter event the extra men add to the confu-

sion in the heading; and since their work is done simultaneously with the other work of the tunnel, it seriously hinders either the drillers or the shovelers, or both. Hence it has become recognized among tunnel men that in most cases timbering seriously impedes the progress of driving, and therefore, although it may be well understood that the roof is dangerous, there is almost always a tendency on the part of those responsible to delay timbering as long as possible. Perhaps the American willingness to "take a chance"—a trait particularly noticeable in our Western States—may be a contributing cause; but the fact remains that the work of timbering is too often delayed until a so-called "accident" brings the necessity forcibly and unavoidably to the front. It is impossible to urge too strongly that all necessary timbering be done promptly, that it *cannot* be done too soon, and that any delay seriously jeopardizes the lives and limbs of the men who have to work under a roof improperly supported.

It is true that in many tunnels the weight of the roof or pressure against the walls has been too great even for the strongest and heaviest timbering, and while this cannot always be prevented, it may often be alleviated by means discussed in the chapter on timbering. But the important thing to consider in these cases, from the viewpoint of safety, is the fact that actual failure of the timbers and caving of supported ground rarely come without warning. Either the timbers will at least be bent quite appreciably before they break, or, as is usually the case, they will crack and splinter and so give unmistakable warning to the miner that the time is approaching when they will collapse. The only way in which accidents can occur in such cases is by carelessness or negligence in heeding the danger signal. It may be said in this connection that, other things being equal, timber which has a fiber that will split, crack, or splinter out, rather than that which has a fiber that will break off short under a transverse strain, is on this account more desirable for such work.

Falls of rock are also caused by cars becoming derailed and knocking out the supporting timbers under a heavy or loose portion of the roof, allowing this material to fall and kill or

injure any men who happen to be underneath. Such accidents are in many cases unavoidable because of the difficulty in preventing derailments. Owing to the lack of illumination, it is usually impossible to see whether the track ahead is clear, and it is therefore necessary to run more or less blindly and assume that nothing has fallen upon the track since the last trip; besides, the mere work of keeping the road-bed of a tunnel track in such shape that its unevenness would no longer cause the cars to jump off would be enormous. The only way, therefore, to lessen these accidents (which are fortunately not so numerous as those from other causes) is to keep the track in as good a condition as possible and to use all reasonable watchfulness and caution in tramming.

Use of Explosives

Next in importance as a cause of injury in tunnel work is the careless, reckless, improper, or ignorant use (or rather misuse) of explosives. Such accidents are of various kinds, the most frequent being those arising from handling, storing, and thawing dynamite, from premature blasts, from misfires, or from suffocation by gases from explosives.

PRECAUTIONS

While the following list, which has been compiled from a number of sources, does not pretend to be complete, it is given here in the hope that it may once more repeat some of the precautions to be observed in the handling and use, not of dynamite alone, but of the accessories of blasting as well.

Handling:

Don't forget the nature of explosives, but remember that with proper care they can be handled with comparative safety.

Don't smoke while handling explosives, and don't handle explosives near an open light.

Don't shoot into explosives with a rifle or pistol, either in or out of a magazine.

Don't attempt to manufacture any kind of an explosive except under the supervision and direction of a trustworthy person who is skilled in the art. Many serious accidents, which have destroyed lives or inflicted injury on persons and property, have been caused by such attempts.

Don't carry blasting caps or electric detonators in the clothing.

Don't tap or otherwise investigate a blasting cap or electric detonator.

Don't attempt to take blasting caps from the box by inserting a wire, nail, or other sharp instrument.

Don't try to withdraw the wires from an electric detonator.

Storing:

Don't leave explosives in a wet or damp place. They should be kept in a suitable, dry place, under lock and key, and where children or irresponsible persons cannot get at them.

Don't store dynamite boxes on end, as this increases the danger of nitroglycerine leakage from the cartridges.

Don't store or handle explosives near a residence.

Don't open packages of explosives in a magazine.

Don't open dynamite boxes with a nail-puller or powder cans with a pick-axe.

Don't store or transport detonators and explosives together.

Don't store fuse in a hot place, as this will dry it out so that uncoiling will break it.

Don't keep electric detonators, blasting machines, or blasting caps in a damp place.

Don't allow priming (the placing of a blasting cap or electric detonator in dynamite) to be done in a thawing-house or magazine.

Thawing:

Don't use frozen or chilled explosives. Most dynamite freezes at a temperature between 45° F. and 50° F.

Don't thaw dynamite on heated stoves, rocks, sand, bricks, or metal, or in an oven, and don't thaw dynamite in front of, near, or over a steam boiler or fire of any kind.

Don't take dynamite into or near a blacksmith shop or near a forge.

Don't put dynamite on shelves or anything else directly over steam or hot-water pipes, or other heated metal surface.

Don't cut or break a dynamite cartridge while it is frozen, and don't rub a cartridge of dynamite in the hands to complete thawing.

Don't heat a thawing-house with pipes containing steam under pressure.

Don't place a "hot-water thawer" over a fire, and never put dynamite directly into hot water or allow it to come in contact with steam.

Loading:

Don't allow thawed dynamite to remain exposed to low temperature before using it. If it freezes before it is used, it must be thawed again.

Don't fasten a blasting cap to the fuse with the teeth or by flattening it with a knife; use a cap crimper. The ordinary cap contains enough fulminate of mercury to blow a man's head or hand to pieces.

Don't "lace" fuse through dynamite cartridges. This practice is frequently responsible for the burning of the charge.

Don't explode a charge to chamber a hole and then immediately reload it, as the bore-hole will be hot and the second charge may explode prematurely.

Don't force a primer into a bore-hole.

Don't do tamping with iron or steel bars or tools. Use only a wooden tamping stick with no metal parts.

Don't handle fuse carelessly in cold weather, for when it is cold it is stiff and breaks easily.

Don't cut the fuse short to save time. It is dangerous economy.

Don't worry along with old broken leading wire or connecting wire. A new supply will not cost much and will pay for itself many times over.

Firing:

Don't explode a charge before every one is well beyond the

danger line and protected from flying débris. Protect the supply of explosives also from this source of accident.

Don't hurry in seeking an explanation for the failure of a charge to explode.

Don't drill, bore, or pick out a charge which has failed to explode. Drill and charge another bore-hole at least two feet from the missed one.

Premature Explosions

It is very often difficult to determine just what are the causes of any particular premature explosion, because in such cases the persons responsible for the explosion rarely survive to tell the tale, and even eye-witnesses are scarce; but carelessness in handling the dynamite in the heading is no doubt the most potent factor. In many cases the so-called accident does not result from the first instance of carelessness or of recklessness, but is the disastrous climax of a series of practices that have become habitual, so that persons knowing the common disregard for dynamite on the part of the men who handled it and were killed are able to draw very accurate conclusions as to the probable cause of the "accident." As an example of this, we cite the case of two men who were accustomed to throw sticks of dynamite to each other along the tunnel, over distances of fifteen or twenty feet, especially if visitors with "nerves" were present. But even at other times, perhaps because of long familiarity with dynamite and hence a contempt or disregard of its great dangerousness, the sticks were thrown to each other rather than have the trouble to walk the few intervening feet. The practice was finally stopped, however, as far as these two personally were concerned, by a disastrous explosion in which they were blown almost to atoms, and which (judging from the subsequent appearance of the tunnel) was probably caused by the detonation of a stick falling near the full supply for the entire round.

Another cause of premature explosions is the practice of carrying dynamite to the face of the tunnel in a box or sack

and dropping it quite roughly to the ground at the end of the journey. This contempt is also bred, no doubt, by familiarity. It is true that oftentimes gelatine dynamite is not so sensitive to direct shocks as one might imagine, and that many times it will stand very rough usage without detonation; but in other cases, and there are very many of them on record, serious explosions have ensued when the care in handling might almost be called extreme. It is therefore neither safe nor advisable to rely in any degree whatsoever upon the "inertness" of dynamite, but at all times great care should be exercised in handling it, if not out of regard for one's own security, then for the sake of the lives and safety of fellow workmen. Nor is it possible to condemn too strongly the practice of carrying the denotators or the primers (sticks of dynamite containing a detonator and a fuse) in the same bundle with the rest of the supply of explosive for the round. They should always be brought in separately and should under no circumstances be placed in the same box, or even near together, after reaching the heading. Many serious accidents have resulted through disregard of this rule.

A certain amount of risk must always attend the loading of a bore-hole with dynamite, especially during the insertion of the primer, but much of the danger which often needlessly accompanies this work can be minimized or avoided by care and caution in its performance. It is, of course, essential to efficiency that there shall be no air spaces in the charge of explosive when it is finally ready for detonation, and in order to insure this the dynamite must be rammed down so that it fills all the unequal spaces in the bore-hole; but the packing should always be done by pressure rather than impact, for some miners use a tamping bar as if it were a javelin. But even when *pressing down* the charge, great care must be taken that too much force is not employed, especially when a cartridge seems to stick in a hole; for should it become suddenly loosened, the miner might not be able to recover himself in time to prevent its being rammed hard against the bottom, with diastrous results. Anything more than light pressure should never be given the primer, and

under no circumstances should it or the succeeding cartridge be struck a blow with the rod.

Irregularity in the rate at which fuse burns is also a cause of premature explosions. Different makes and brands of fuse burn at greatly varying rates and a miner accustomed to a slow-burning fuse will perhaps not realize the necessity of cutting the faster fuse longer, so that he may have time enough to reach a place of safety before the detonation takes place. But there are several causes which may produce variations in the burning rate even of the same brand of fuse. For example, experiments conducted by the Bureau of Mines * show that mere confinement in a closed vessel is sufficient to cause a fuse to burn three or four times faster than its normal rate. It is true that under ordinary conditions of mining variations of this magnitude are not apt to be reached, but irregularities of 20 per cent. or even 30 per cent. are quite possible, and in long bore-holes in which a quantity of tamping is used, and especially if it be of a type impervious to the escape of the gases (such as closely packed wet clay), the variation may be much greater. Therefore, where such tamping is used, the rate of burning may be increased to a dangerous extent, unless due allowance be made for this extra speed. But even more important is the effect produced by mechanical injury, which is more apt to be a common occurrence. Mere bending of fuse (if it is in proper condition for use), such as might result from coiling it near the collar of the hole to prevent its being struck by flying rock from other blasts, or even placing it with some force within the hole, has but little if any effect upon the fuse; but abrasion, blows, or too great pressure produce serious variations in its rate of burning and in some cases may even cause it to burn almost instantaneously. It is therefore essential that none but fuse in good condition ever be brought into the heading, and that care be taken while it is there to see that it is not injured by rocks or tools falling upon it, and that it is not abraded or otherwise injured with the tamping bar while the hole is being loaded.

Mention must be made of the apparently obvious danger of

* Technical Paper 6.

reloading a bore-hole before it has had time to cool off sufficiently from a previous blast. In tunnel work this applies particularly to the "guns," as they are called—the ends of holes that have not broken to the bottom with the first explosion—and accidents, either through carelessness in not examining the holes or a desire for haste overcoming better judgment, have been caused by too early reloading of these guns after the first blast.

Misfires

Many deaths and injuries are caused by the subsequent detonation of a charge of dynamite which failed to explode at the proper time, though misfires do not mean accidents unless the unexploded dynamite is detonated unexpectedly in some way. Sometimes this is done by drilling into it during preparations for the next round, or by striking it on the muck pile where it has been thrown by the blast from a neighboring hole, or perhaps by the sudden explosion of a delayed shot from a fuse that has long been smoldering.

A large portion of these misfires can be traced directly to some injury to the fuse. The insertion of the primer into the hole, fuse-end first, often causes a crack in the fuse at the sharp bend thus produced (and the danger of cracking it in this way is especially great when the fuse is cold or the hole is full of cold water), or sudden and rough uncoiling of the fuse in cold weather will usually cause it to break. It is therefore obvious that cold fuse should not be bent, twisted, or roughly handled. It is claimed by some persons that misfires are caused through the fuse being cut off ahead of the fire in it by the explosion of a neighboring hole, so that consequently the charge of dynamite fails to explode. There is some question whether this really happens or not; but if it does, it is a pretty strong argument that the hole in question was probably misplaced, for if it was properly located, only in rare instances, if ever, would enough of the hole be shot away to cut off the fuse ahead of the fire. It is also claimed, and with somewhat more reason, that the fuse is apt to be torn out by flying rocks from the explosion of other holes, but this can be largely obviated if the fuse is properly coiled, as

it should be, close to the mouth of the hole before it is "spit."

The failure of a fuse properly to ignite a detonator is often caused by improper storage. When the asphalt water-proofing composition used in some fuses gets too hot, it becomes viscid and agglomerates the powder grains in the core of the fuse, and thus delays, and in some cases actually prevents, the fuse from burning. Experiments conducted by the Bureau of Mines * indicate that prolonged exposure at a temperature of 60° Centigrade is sufficient to cause a marked retardation in the rate of burning. It follows, therefore, that fuse should not be stored near boilers, steam pipes, or other sources of heat, where the temperature is apt to be high. The effect of cold is likewise deleterious, for it renders the asphalt composition brittle and liable to crack, and these cracks either decrease the rate of burning by permitting the gas from the powder core to escape more readily than usual, or, if they are large enough, they may stop the travel of the fire entirely. The fuse should be carefully protected from moisture during storage; for, with water-proof fuse of the type almost universally employed in tunneling, if the dampness once gets into the powder train it is very difficult to get it out. As the fuse burns, this moisture is driven ahead of the fire in the form of steam, and even if it does not thus accumulate in sufficient quantity to quench the fire in the fuse, enough of it may be driven into the detonator to prevent its ignition and thus cause a misfire.

Misfires originate in many cases from improperly prepared primers. Before inserting the fuse into the detonator, an inch or two should be cut off and thrown away, for gunpowder (which forms the core of the fuse) being somewhat hygroscopic, the end of the fuse may have gathered sufficient moisture to quench the burning powder or prevent the ignition of the cap; this cut should be made with a sharp cutting tool squarely across the fuse, for if cut diagonally the point may curl over the end of the fuse when inserted in the detonator and thus prevent the spit of the powder train from reaching the gun-

* Technical Paper 6.

cotton (or the mercury fulminate) in the cap, causing a misfire. Care should also be taken that the powder grains in the end of the fuse do not leak out after the fuse is cut, for this would tend to weaken the force of the spit into the detonator and might prevent its ignition. The free end of the cap should be carefully crimped around the fuse with a proper crimping tool, so that it will be tight enough to hold the detonator and the fuse together and keep out moisture, but the crimping should not be tight enough to cut off the powder train in the fuse. This is particularly liable to happen when a narrow crimping tool is employed, which presses a very narrow groove in the detonator and the underlying fuse. There are tools on the market which have a crimping face of at least a quarter of an inch, and the extra purchase price of several of these tools would be no more than the cost of the explosive wasted by a single misfire, to say nothing at all about the possible loss of life that might arise from it. It is of course obvious that the teeth or a knife should never be used for crimping; for, as we have said, there is enough explosive in an ordinary detonator to blow a man's head or hand to pieces. After crimping, the detonator should be buried in the end of the stick of dynamite with its axis parallel to that of the stick, and the top of the detonator should be flush with the top of the dynamite; for if the cap is buried deeper, the explosive is liable to become ignited from the side-spitting of the fuse before it is properly exploded by the detonator, which not only destroys the efficiency of the explosive, but causes a larger amount of gases, especially those most dangerous to the men who must breathe them. It is also important to use a detonator of sufficient strength. Although 3 X caps were considered strong enough for straight nitroglycerine dynamite, the less sensitive gelatine dynamite requires a much stronger detonator to explode it properly. For this reason nothing weaker than 5 X caps should ever be used with gelatine dynamite and the universal experience is that better results have been obtained where a change has been made to an even stronger detonator. These insure the complete detonation of the explosive and thus produce only a minimum amount of dangerous gases.

It is very difficult to count the explosions during blasting and be sure that the charges have all been detonated, so that it is not always possible to determine whether or not there has been a misfire. For this reason the face, or as much of it as is not covered by the débris resulting from the blast, should at once be inspected for evidences of missed holes, and it should be carefully watched during the removal of the muck. If a missed hole is discovered, under no circumstances should an attempt be made to pick out the material. If no tamping has been used, as is usually the case in tunneling, a stick of dynamite containing a detonator should be inserted in the hole and exploded *at once;* if tamping has been employed, another hole should be drilled and blasted at least two feet from the missed one. In picking down the muck pile the pick should be handled as if it were a hoe and not like a sledge hammer; *i.e.*, the material should be pulled or scraped down and never struck violently with the point of the pick. In this way, should there happen to be a piece of unexploded dynamite in the débris, there is much less danger of an explosion resulting from it, with a corresponding injury and loss of life. The importance of this precaution cannot be too strongly emphasized. Should a piece of dynamite be discovered in the muck, it should be removed carefully and handed to the foreman, who should at once take it to a safe place, and the most *extreme* care should be used if a piece of fuse accompanies it or is discovered near it, for this would indicate that an unexploded detonator may possibly still be inside of the stick of dynamite, the danger of which is obvious. Under no circumstances should a new hole be started in the remnants of a former hole that has ever held dynamite; for although the inference is always, of course, that the dynamite has been detonated, still there remains a *chance* that this might not have occurred—a chance not so slight as might ordinarily be supposed, to judge from the number of accidents traceable to this source. And even if a rod is used to test the hole, it might encounter a small rock and, by thus *seeming* to show the bottom of the hole, fail to reveal the dynamite beneath.

Suffocation by Gases from Explosives

Suffocation from the gases produced by explosives is a common source of injury in tunnel work. Cases of this kind are familiar to most miners; it is usually called "powder headache" in its mild form and produces little more than temporary inconvenience, but in severe cases it has been known to produce death within a very short time. In the chapter on blasting it has already been explained that the harmful gases resulting from the complete detonation of dynamite under normal conditions are usually carbon dioxide and carbon monoxide; that although the former will not support respiration, and when present in sufficient quantities may cause unconsciousness and even death, it has no very injurious effects when sufficiently diluted; that the latter is exceedingly dangerous and even small amounts of it may prove fatal if breathed for a sufficient length of time. It is this gas which probably causes the familiar symptoms after a dose of "powder smoke." By a reference to the table on page 238 it will be seen that gelatine dynamite, the type almost universally used in tunnel work, under proper conditions generates a comparatively small amount of the more dangerous gas. Experiments conducted by the Bureau of Mines indicate that even this can be obviated by a slight modification in the chemical composition of the gelatine dynamite. But even if *such* a dynamite is not completely detonated (either through the use of too weak a detonator or for any other cause), and especially when it burns rather than explodes, a much greater amount of monoxide is formed and, in addition, a number of other harmful gases are developed, among which may be mentioned the dangerous peroxide of nitrogen. It is therefore essential that detonators of sufficient strength be employed to explode the dynamite completely, and that every precaution be taken to prevent the dynamite from taking fire through the side-spitting of the fuse or in any other manner.

The deadliness of the gases resulting from explosives improperly detonated may be illustrated by describing one occurrence which is known to have cost nine lives. A study of

the attendant circumstances, as described in a communication to the writers, indicates that the explosive, or a large portion of it at least, must have burned rather than detonated. Gelatine dynamite was employed and the charge was even smaller than previous blasts of which the men had inhaled the fumes without serious effects, but in this case the fumes are described by the men as having been brownish-yellow rather than the usual grayish or bluish-white. After igniting the blast the men retired about 500 feet to wait for the smoke to clear, and while they were waiting the smoke drifted slowly over them, and then, owing to some change in the current, drifted slowly back again. The men soon felt the usual symptoms of carbon monoxide poisoning—slight choking, nausea, profuse perspiration, and headache—but they all revived upon reaching the open air about an hour and a half after the blast was fired. Within a short time, however (and in one case before the man could walk to the bunk-house), the men began to cough up bloody mucus and exhibit other symptoms of nitrogen-peroxide poisoning, and in less than three days nine of the thirteen men who had been in the tunnel and exposed to the fumes had died. The four who escaped were either not exposed to the gas for the full time, or else found some other source of air supply which served partly to dilute the gases; but some of these men, as well as those who went in with the motor to bring the men out, were ill for days and even months after the catastrophe. A full discussion of the customary symptoms that accompany poisoning from nitrogen peroxide and carbon monoxide, and their comparison with the symptoms exhibited by the men, will be found in the April, 1911, number of *Colorado Medicine*, and it is the opinion of physicians who have studied this case that many swift deaths among miners, formerly diagnosed as pneumonia, may really have been caused by the inhalation of gases from burning dynamite.

Suffocation by Gases and Other Sources

Although the chief source of any carbon monoxide that is liable to be encountered in tunnel work is usually to be found in the dynamite employed, there have been cases in which this dangerous gas was generated by the combustion of oil and grease in the air-receiver and transmitted to the heading by the compressed-air pipe. The causes of such combustion have been fully discussed in the chapter on air compressors, so that it need merely be mentioned here that the ignition of accumulated oil and grease is generally due to faulty valves in the compressor. These permit leakage back into the cylinder of the warm compressed air, which, upon being recompressed, becomes still hotter, so that after a time the temperature of the air in the receiver may be built up far beyond the ignition point of the lubricant employed. If an explosion does not then ensue, the oil on the sides and bottom of the receiver will burn and produce carbon dioxide or carbon monoxide, as the case may be, either of which jeopardizes the safety of the miner in the heading. It is, therefore, necessary to inspect the valves of the compressor regularly; what is more, dependence should never be placed on the compressed-air line for tunnel ventilation.

There are a number of tunnels in which natural deposits of gas have been encountered, the two kinds most frequently found being carbon dioxide and hydrocarbon gases. The former is, of course, chiefly dangerous because of the possibility of the men being overcome by suffocation, but this can largely be obviated by sufficient ventilation, although sometimes at a considerable additional expense. As an instance in point, one of the tunnels on the Los Angeles Aqueduct might be mentioned, in which currents of carbon dioxide were encountered in a series of crevices across a zone about 150 feet wide. In order to make it possible for the men to work in the tunnel, this zone and 300 feet on each side of it were tightly sealed with concrete; in addition, it was found necessary to leave an annular space back of the concrete in the center of the gas zone, to which a blower was connected that constantly exhausted the gas during the driving of

the tunnel, while an additional blower forced in fresh air to the men. When either of these machines ceased operating, it was necessary for the men to get out of the tunnel as fast as possible, but as long as they were kept running the air was sufficiently pure.

The chief danger from hydrocarbon gases lies in their explosibility, but they are so commonly met with in coal mining that precautions to be taken in their presence are fairly well known. A rather unique method of dealing with this problem, however, —a method which is well worth a description—was employed in one of the tunnels examined by the writers.

The gas was encountered in a zone approximately 2,300 feet in extent, through about 500 feet of which oil could be distilled from the rocks, although it did not flow of itself. The gas was highly explosive and had an odor of kerosene or gasoline rather than that of crude petroleum. The largest quantities of it came into the tunnel immediately after blasting, from the rock broken by each new round, and the maximum accumulation was approximately 30,000 cubic feet. There appeared to have been no particular seepages in the gaseous zone, but rather an unknown quantity ahead of the work that had always to be reckoned with. Since the gas was highly explosive, extra precautions had to be taken for the safety of the men at work. The mere restriction of permitting no open-flame lamps and requiring safety lamps in the tunnel was not considered sufficient here, although that is the usual practice in coal mines where similar gases are encountered, because the very nature of the rock was such as to cause sparks from a pick or from the starting of a drill hole, and such sparks were thought to be sufficient to ignite the gas and produce an explosion. The expedient adopted was to explode the accumulation after each blast and to burn any new gas as fast as it appeared in the tunnel during the remainder of the work.

For this purpose the tunnel was wired from the portal to the heading with a 550-volt circuit, into which were introduced at intervals of about 200 feet, throughout the entire gas-bearing section, a number of arcing devices. Any ordinary street arc lamp could have been adapted for this work, provided that the

carbons were not exposed for more than two inches; otherwise the concussion from ordinary blasting, as well as from the gas explosions, would have broken them. The use of one soft and one hard carbon was found to give the best results. This system was operated as follows:

Immediately after blasting, a fire boss and his helper took charge of the tunnel. Waiting thirty minutes after the blast was fired, they turned a current of electricity through the arc line by means of a switch at the portal. Since the arcs were purposely placed in series, in order to make certain that if any one of them burned they must all necessarily do likewise, an ammeter at the control switch showed whether or not they had lighted. If such was the case, an explosion, which sometimes would be a severe one, generally ensued. But whether this happened or not, the switch was always opened for fifteen minutes and then closed a second time as an added precaution, although a second explosion never resulted from this operation. With the line dead once more, the two men carrying safety lamps then proceeded to a protected station approximately half-way to the heading, where they again sent a current through the arcs. A few explosions resulted from this practice, but they were unusual rather than customary. After having made this test, the fire boss and his helper then proceeded to the heading, testing the entire tunnel for gas by means of the safety lamps they carried. They would ordinarily find an accumulation of gas in the heading, extending back a distance of 125 to 150 feet, because the nearest arc could not be placed much nearer to the heading than the greater of these distances on account of the danger of the carbons being broken by the concussion from the blasting. The fire boss would then take an arc which was kept 150 feet from the face and which was attached to the circuit by an armored cable, and place it over the muck pile, when the two men returned again to the midway station and once more closed the circuit and ignited the remaining gas. Then, and then only, and *with all the arcs burning*, they returned to the heading and placed torches as near the roof as possible at intervals of about 150 feet throughout the gaseous section. These

torches were lighted from the arcs, and the men were not permitted to light them in any other way, or indeed to carry any other means of lighting them into the tunnel, thus insuring that there should be open fire in the heading before the torches were lighted. By this time all the seepages that were strong enough to support a steady flame would have been lighted and would be burning, while the gas that came from pockets that could not sustain a flame would be ignited by the torches before it could accumulate in any quantity. The fire crew then returned to the mid-station, where they extinguished a red light and lighted a white one, indicating that the tunnel was safe for the incoming crew, for no one but these two men was allowed in the tunnel beyond this point unless the red light was out and a *particular white one* was burning.* The fire crew were allowed four hours for this work, although it did not ordinarily take them so long.

The working crew, upon reaching the heading, ordinarily found the muck pile too hot to handle, if, indeed, it was not actually in flames, for it burned usually for from one-half to two hours after each blast, while once, at least, it burned for fourteen hours. After it had been cooled sufficiently by streams of both air and water, the machines were set up and the round of holes drilled in the regular manner. Any gas that developed during the drilling of a hole was lighted as soon as the hole was completed, and if sufficiently strong to support a flame, it would burn until the end of the shift, and at one time as many as six out of eight holes on the top round were burning like blow-torches, giving flames six to eighteen inches in length. When the round was finished, the holes had to be cooled before loading. This was accomplished by turning water and air lines through ordinary blow-pipes, both into the holes and over the face of the tunnel. The flames were, of course, extinguished by this process, and as soon as the gas had accumulated in the tunnel sufficiently to become apparent in a safety lamp placed near the roof, about thirty feet from the heading, it was ignited by a torch, and the

* To obviate danger through any accidental extinguishing of the red light without the knowledge of the fire crew, and before the tunnel was safe.

resulting flames were at once put out again by air and water. This process was continued until the holes were cool, when they were at once loaded as rapidly as possible, and fired, the fuses, in doing so, being always lighted from near the bottom of the tunnel.

Although the fact that there were no accidents in driving through the gas-bearing zone after the installation of the "safety arcs" shows that this system was efficacious in this particular instance, it is not one that can be recommended unqualifiedly for general use. In the opinion of engineers who have made a special study of the question of safety in mining, the use of anything but safety lamps, or their equivalent, in mines or tunnels where explosive gases are known to exist, is never without risk, while the practice of burning the gases as fast as they make their appearance is in itself extremely hazardous. Indeed, the fact that no disastrous explosion occurred under this system seemed to them remarkable. Aside from this, it is obvious that long delays were necessary before the men could start to work, and even after they had reached the heading, the heat must have greatly decreased their possible efficiency. A less dangerous method of handling a similar situation, and one that would probably prove more economical in the end if everything were taken into consideration, would be the installation of a ventilating system large enough to dilute to harmlessness several times the amount of gases ordinarily encountered, combined with the absolute prohibition of any but safety lamps in the tunnel, and the firing of all blasts by electricity.

Haulage

A large proportion of the injuries attributed to tramming is caused by the practice of riding on the cars, and especially upon the loaded ones. When riding upon the top of a full trip, a man is always in danger of a serious injury at every low place in the roof, and if he is riding between the cars (or any place but the rear end) he is liable to be jarred from his foothold and dragged under the cars, while he has little chance of escape in case of derailment. A certain risk of derailment is unavoidable

in tunnel work, partly because of the insufficient illumination under which tramming is generally carried on, and partly because of the difficulty, almost the impossibility, of keeping the road-bed in good condition or the track clear of small obstructions. Even when riding upon empty cars there is serious risk whenever the miner sits upon the ends or sides and allows his feet to hang over; the safest way is to sit inside of the car and to crouch low enough to avoid being struck by any jutting place in the roof. The driver, or "mule skinner," is often compelled to ride upon a loaded trip and sometimes at the front end of the train in order to be near the animal he is driving, but the extra hazard of this position should be fully realized and extra precautions taken. The practice observed on the part of some drivers, of riding with one foot on the bumper and the other on the chain by which the mule is attached to the first car of the trip, the danger of which is obvious, cannot be too strongly condemned, and it should be made cause for the instant dismissal of any driver caught doing it. It ought not to be necessary to mention the danger of attempting to jump on or off a moving trip of cars, because the chances in such a case of a man missing his footing and being caught or dragged under the cars, or of breaking an ankle or leg in the uncertain light, should be so clearly seen that no one ought to consider the risk worth taking; but the number of injuries arising from this cause shows only too well that this precaution is habitually disregarded.

Great care is necessary during the operation of placing a derailed car back upon the track. It is very easy for a miner to strain or otherwise injure himself if he attempts to do this without getting some one to assist him. Also in handling a derailed car that is full of rock there is danger of block or crowbar slipping and allowing the car to drop suddenly on the miner's foot or hand, if indeed it does not topple over completely and crush him against the side of the tunnel.

Failure to allow sufficient room to a passing trip of cars is also a frequent source of injury. Before going into a strange tunnel the miner (or any one else for that matter), if he is not accompanied by some one familiar with the tunnel, should always

ascertain upon which side of the track there is the most room, and in meeting a passing trip should always give an animal pulling it all the space possible, to avoid being tramped on or kicked by the horse or mule or being caught between the cars and the walls of the tunnel. It is also advisable to hide any light when meeting a horse or mule, for there are some animals that are afraid, especially of the high-powered acetylene lamps that are coming to be used almost entirely in tunnel work; they will balk when coming toward one and cause a serious mix-up, since the cars behind cannot always be stopped at once. Respectful attention in a tunnel, as on the surface, should always be given the heels of animals whether moving or at rest, and it is best to speak to them when approaching from behind, for many serious injuries have been caused by passing too close to nervous animals without warning. The driver also, when turning a horse or mule around in a heading, should watch carefully to see that he is not stepped on; inane as this advice sounds, many really serious accidents have resulted from just this simple cause.

Electricity

An examination of reports of electrical accidents in tunnel work shows that in the majority of cases the shocks were caused by the trolley wire. This is not surprising when one considers the many factors which unite to make electricity especially dangerous underground. In the first place, the earth is almost always used to complete the return circuit, and therefore, if the miner inadvertently touches any portion of electrical apparatus that is charged with current, and if he is not well insulated from the ground, he will certainly get a shock the intensity of which depends upon the voltage or pressure of the electric current and the incompleteness of his insulation from the earth. It is to be expected that the trolley wire should be the chief source of electrical shocks, for it carries a current sometimes as high as 600 volts without any insulating or protecting covering whatsoever and generally without a guard or shield of any sort, while it is usually placed less than a man's height from the floor and has a rail beneath it to form a return circuit even

better than the earth. Then, too, tunnels are generally damp or wet, so that a man is rarely well insulated from the ground; the light at best is poor and one cannot always see the wire as he approaches it, while the space is so restricted that a man in walking in and out must keep his head close to the wire when, at the same time, the most of his attention must needs be given to the question of footing. Then, too, when climbing into or riding in cars, which in tunnel work are almost always of metal and furnish excellent electrical connection with the rails, one's head must pass close to the live wire. The carrying of metal tools, such as crow-bars or drill steel (although picks and shovels are equally hazardous if the wooden handles are wet), is also the cause of many shocks through their accidental contact with the trolley, and this is especially liable to happen if such tools are carried on the shoulder. It is therefore important, when walking in a tunnel where a trolley wire is installed, constantly to bear its existence in mind and take every precaution to avoid contact with it by hand, wet clothing, or tools.

In addition to the trolley wire, there are in tunnel work other sources from which electrical shocks may be received. Wherever the heading is illuminated by electricity, the lights are usually grouped in a cluster and connected to the main circuit by means of a flexible cable, so that they can be easily removed to prevent breakage during blasting. The wires of the cable are, of course, insulated in such cases, but owing to the rough usage they receive, it very often happens that the insulation is damaged or scraped off, leaving the bare wire exposed. Even if the injury is *not* severe, it is often sufficient to permit a considerable leakage of current from which a person handling the cable may receive a severe shock. Such wires are the more dangerous because, supposing them to be protected, one is more apt to handle them carelessly. The men who remove these wires preparatory to blasting, and replace them afterward or otherwise adjust them, should examine them closely and not touch any place where the insulation has become damaged. Shocks are also caused by motors, transformers, or other pieces of electrical equipment which are supposed to be

safe, but which may have become charged with current, or in the adjusting or repairing of switches and other similar devices, parts of which are known to be alive, but which are touched accidentally in the course of the work. In handling apparatus of this sort, a workman should carefully insulate or otherwise protect himself from the current and should try to handle the apparatus in such a manner that any involuntary muscular reaction from a shock will throw him clear of its live parts rather than bring him in closer contact with them. Although electric locomotives are usually in such perfect contact with the rails that a person touching any accidentally charged part of the frame will rarely receive a shock, there are times (as, for example, when there is a considerable amount of dirt or sand on the rails) when the locomotive is almost completely insulated from them; in such a case any one coming in contact with a live portion of the frame or of the draw-bar, or even with one of the cars coupled to the locomotive, may receive a severe shock which is apt to be all the more serious because it is unexpected. For this reason the touching of such equipment should be avoided when not actually necessary.

Mention should be made here of the immediate steps to be taken in case a man has received a severe electric shock and is perhaps lying unconscious and apparently dead from its effects; for it is often possible by prompt treatment to revive and restore a man in this condition when otherwise he might fail to recover consciousness. The best methods suggested for such cases may be found in Miners' Circular 5, published by the Bureau of Mines, a copy of which may be obtained free upon application to the Director, Bureau of Mines, Washington, D. C.

Fire

The chief danger to the men in a tunnel from fire is the possibility of the buildings at the surface becoming ignited. These structures are, of course, subject to the same causes of fire as ordinary buildings, such as the careless handling of matches or lights, spontaneous combustion of oily waste wherever it is allowed to accumulate, or the short-circuiting of electrical wires,

not to mention the risk of forest fires in heavily timbered regions. At a large majority of tunnels now being driven, the blacksmith shop, the store room, the boiler house, or other buildings, are situated much closer than the 200 feet which *should* separate them from the tunnel portal, and in many districts, especially where the winter snowfall is heavy, they are directly connected with the tunnel by snow-sheds usually constructed of wood. At such tunnels, also, other means of exit than the portal are seldom provided, so that in case of fire in these buildings men are penned up in the tunnel and, in the customary absence of a fire door, they are in serious danger of suffocation from the gases and smoke produced by the conflagration. It is, therefore, essential, and in some States it is fortunately required by law, that in all tunnels where combustible structures must be erected nearer to the portal than 200 feet, there should be a separate exit at least 200 feet away, and a fireproof door should be provided in the tunnel that can be closed from a distance. At the same time a sufficient water supply should always be maintained to put out an incipient fire, and hydrants with a coiled 1½-inch hose and a nozzle should be placed not less than 40 feet and not more than 100 feet from each building or group of buildings.

Although most tunnels are themselves practically fireproof (except where timbered), and hence underground fires in tunnel work are not common, it is, nevertheless, important even here to guard against the dangers of fire. Whenever underground fires do occur in tunnels, they usually start in some small way, either from candles or lamps being placed too near the posts or caps of a timber set, or from throwing a match or the coals from a pipe into a pile of rubbish, hay, or other combustible material which may in turn ignite the timbering. Although such fires can usually be extinguished at once and before any great damage or injury has resulted, if their presence is discovered soon enough and if means are at hand for that purpose, it is much better to prevent the ignition by obviating causes. Therefore, combustible rubbish should not be allowed to accumulate in the tunnel and any supply of hay for the use of mules or horses underground should be carefully confined in a bin pro-

vided for that purpose, while open lights or smoking should not be permitted in their neighborhood. Candles or torches should never be left burning near timbers, while the practice of wedging a lighted candle between two nails driven into a post should be cause for the instant dismissal of the guilty persons.

Water

Water under pressure is another source of danger in tunnel work, and men are hurt in jumping back to avoid the rocks and other débris often carried with it, or are perhaps buried under an accompanying rush of mud and sand. A good example of this may be found in the records of a foreign railway tunnel, where a cleft filled with water, sand, and gravel was encountered and the ensuing sudden and violent inburst of these materials filled up more than a mile of the tunnel in a very few minutes, burying twenty-five workmen and their tools beyond all hope of recovery. A somewhat similar occurrence in one of our American tunnels, although fortunately with less fatal results, was likewise due to water. The tunnel caved in at a point about 4,000 feet from the heading, but the men working there were warned in time to escape, although they had barely reached safety before the tunnel became entirely closed. When this happened, the mass of rock, composed chiefly of soft clay and running shale impervious to water, cut off the main flow in the tunnel, which was approximately 2,700 gallons per minute. As soon as the portion of the tunnel between the cave and the heading became filled with water, the full pressure of the head in the mountain over the tunnel was exerted against the dam, forcing it down the tunnel until the pressure was relieved. The additional length of the débris then offered greater resistance and remained stationary until the pressure had again accumulated enough to move it, and this process was repeated until 440 feet of tunnel had been filled. Several attempts were made at first to relieve the pressure by inserting a section of ventilating pipe at the top of the dam; but after several men had narrowly escaped burial by the rush of mud as the dam moved forward, this scheme was abandoned and the tunnel was sealed

up by a concrete bulkhead, the men being protected by a temporary bulkhead of wood during the construction of the permanent one.

In driving through limestone and dolomite it is not unusual for a tunnel heading to tap immense caves filled with water, mud, and sand. In such cases the volume of the fluid mass flowing into the tunnel is determined by the size of the opening, while its velocity is proportionate to the head. Under a pressure of 300 or 400 feet the cutting action of the rock particles and sand carried by the water soon enlarges even a drill-hole to a size that permits the filling up of the heading in an incredibly short course of time. When a round of shots breaks into a cave of this kind, the heading and perhaps the completed tunnel for a distance of hundreds and sometimes even thousands of feet back from the face may be filled so fast that the escape of the workmen would be impossible if they were in the face. Fortunately, however, at the time of greatest danger, viz., shot firing, the men are always out of the heading.

When an underground cave or reservoir filled with water, mud, sand, and loose rock is tapped in a tunnel heading one of two things occurs: generally the cave or reservoir empties itself completely into the tunnel and, after the flow is over, the solid matter which the flood leaves behind can easily be shoveled up and hauled out; but it sometimes happens that the volume of solids is so great that the tunnel is completely choked up before the reservoir is emptied. In these cases, when the flow of water ceases, the men are usually set to work cleaning up the material with which the tunnel has been filled, but when this cleaning-up process advances sufficiently to weaken the dam which is holding back the flood, a new outburst occurs and, because the passageways have already been opened, the second outbreak is often more violent and dangerous than the first. If this operation were repeated often enough, the cave or reservoir would of course be drained and the heading be regained, but in many instances the operation of attempting to regain the heading has been found so dangerous that it has been abandoned and a curved tunnel put in to pass around the danger point.

In the Cowenhoven tunnel, when the heading was in dolomite, caves of this kind, filled with water and dolomite sand, were frequently encountered, and it was no uncommon thing to have the tunnel completely filled for hundreds of feet back from the face after a round of shots. As soon as the water from the cave which had been tapped drained off, the mud and sand were easily loaded up and work in the face was resumed. On one occasion an immense cave of this kind was tapped by a drill-hole in a long cross-cut which was being driven from the tunnel to the Della S. Mine, which, under the pressure and cutting action already described, enlarged so rapidly that the men fled from the face and, a few seconds after, the opening enlarged to a size which permitted the filling of the tunnel with such rapidity that the tunnel cars were hurled back and flattened against the posts. Several unsuccessful attempts were made to regain this face, which finally had to be bulkheaded and the tunnel run around it, as at the Loetschberg tunnel.

In the 1,200-foot level of the Free Silver mine, which was likewise run through dolomite, numerous caves were also encountered, but fortunately, while they must have extended to great heights, their horizontal cross-section was very much less than that of the caves 1,200 feet above. When these reservoirs were tapped with a drill-hole the water would spout out with such velocity that it was impossible to stay in the face, and in a short time the opening would be worn to a size which sometimes increased the amount of water to be handled by the pumps to 3,000 and even 4,000 gallons per minute. At first the noise from the inrushing volume of water was exceedingly terrifying to the men, but "familiarity breeds contempt," and in a short time whenever a cave of this kind was tapped the men simply joined hands to assist each other in maintaining their footing and waded back with the torrent the same as they would do in crossing an extremely rapid stream. Many narrow escapes occurred, but, owing to the precautions taken by the management and workmen, no serious accidents occurred during any of these inrushes.

Intoxication

Although few accidents in tunnel work are traced directly to intoxication, the extent to which it contributes to many mishaps that are ascribed to other causes is perhaps too little appreciated. The fact that a man who has put an enemy into his mouth to steal away his brains is much more likely to be careless or negligent of his own safety and the lives of the men around him is so well established as to need no emphasis. Even a slight degree of intoxication, that might be allowable if the work had to be done on the surface, is dangerous underground, where it is very apt to be greatly aggravated either by the lack of fresh air or by the heat, either of which is common in tunnel headings. Therefore it is essential that a man in such a condition should not be permitted underground and, if discovered there, should be immediately sent out of the tunnel by the foreman, while repeated offenses should result automatically in dismissal.

PREVENTION OF ACCIDENTS

In discussing the prevention of accidents in tunnel work little is to be gained by saying that the manager or the foreman or the miner is solely to blame for their occurrence. The greater responsibility lying, as ever, with those who have the broader vision, the manager or the superintendent is in duty bound to see that the place where the men are to work shall be made as safe as possible and to insist that they, themselves, exercise the greatest care and caution in conducting their work. Then, again, accidents are costly, not only of life and limb, but usually from a financial viewpoint; for in many cases they either seriously hinder the work or cause it to be shut down altogether for months at a time, as, for instance, after a fire, or flood, or cave-in—catastrophes which in many cases could have been prevented, if even but ordinary precautions had been taken beforehand. So, both from the humanitarian and from the economic point of view, safety should come first, and the business of making the

tunnel safe for the men to work in should be considered more important than the driving of extra footage per month. Upon the foreman falls the responsibility of carrying out the manager's orders, of seeing that the men are instructed in the proper precautions to be taken, and that these are constantly and consistently exercised, and, if necessary, of discharging either temporarily or permanently any man who wilfully or habitually disregards them. As for the miner, whose business is shown by statistics to be a hazardous one at best, it is only through the most extreme care on the part of each man, not only for his own welfare but for the safety of his co-workers, that he can hope to escape from the dangers that surround him. Each one has his share, therefore, of the responsibility, and it is only by co-operation between all parties concerned that any progress can be made toward the prevention and reduction of the fatalities and the injuries now encountered in tunnel driving. Since it is impossible to reiterate too often the methods of obviating accidents, the following paragraphs are written directly for the parties most concerned, in the hope of bringing home to them once again some of the more important preventive measures.

Precautions for the Manager or Superintendent

Insist that necessary timbering be done at once and always keep an adequate supply of lumber at hand for this purpose, so that no delay may ensue from the lack of it. See that the minimum amount of explosive is used (in order to prevent unnecessary shattering of roof and walls) and inaugurate a systematic and regular examination of the roof to insure the removal of all loose pieces at once. Have all bent or breaking timber promptly replaced by new posts or caps.

Provide suitable magazines and thaw-houses for explosives.*

Do not permit any disregard of the proper precautions in handling, storing, or using explosives, such as are listed on

* Specifications for such buildings recommended by the Bureau of Mines are to be found in Technical Paper 18, which may be had free on application to the Director, Bureau of Mines, Washington, D. C.

pages 293–96, and see that each man is provided with a copy of these or similar precautions.* Do not permit the transportation of detonators or primers to the heading in the same bundle with the remaining supply of explosive for the blast. Have careful tests of the burning rate of the fuse made periodically, especially whenever a different brand of fuse is purchased, and warn the men of any discovered irregularity. Destroy any damaged fuse at once. Do not store fuse near any source of heat. Prohibit the reloading of a bore-hole before it has had time to cool from a previous blast. Give the men proper tools and have them instructed in the correct way to prepare a primer and see that these instructions are obeyed. Do not *purchase* caps weaker than 5 X for use with gelatine dynamite. See that the proper precautions are taken whenever a missed hole or evidences of one are discovered.

Institute a regular and frequent inspection of the valves on the air compressor and insist that any defective valve be promptly and properly repaired, even at the cost of a possible shut-down, that there may be no explosion of gas or burning of grease in the receiver or pipe-line to produce harmful gases and jeopardize the safety of the men at the heading. Do not delay the installation of adequate auxiliary ventilating equipment when natural deposits of harmful gases are encountered in the tunnel, and this is particularly important when such gases are of an explosive nature. In the latter instance, none but safety lamps or their equivalent should be permitted underground.

Prohibit the men's riding on loaded trips and, whenever possible, provide for their use special cars either propelled by hand or drawn by a motor. Do not permit them to jump on or off moving cars, nor the drivers to "ride the chain." Tell all new men the proper side of the tunnel to take when meeting a trip, and caution them to shield any bright light when so doing.

If there is a trolley wire or other electrical apparatus in the tunnel, caution the men against its danger, and do not allow

* A Miners' Circular containing these precautions may be obtained free from the Director, Bureau of Mines, Washington, D. C., by forwarding the names and addresses of the men for whom it is desired.

them to carry tools on their shoulders when passing in or out. See that the cables or wires leading to any temporary or movable cluster of lights in the heading are kept in good repair. Instruct the men, and especially the foremen, in the proper methods of resuscitation in case of electrical shock.

Prohibit the accumulation of combustible rubbish anywhere in the vicinity of buildings or timbering and see that the supply of hay is properly confined to prevent danger from fire. Do not construct any wooden buildings nearer than 200 feet from the mouth of the tunnel, unless such are absolutely necessary, in which case provide a separate exit from the tunnel at least 200 feet away, with a fire door so arranged that it may be closed from a distance. In either event, provide an adequate water supply, with hydrants and hoses, at suitable distances from the several buildings.

Exercise great precaution when driving toward a place where a flow of water is likely to be encountered that might carry with it a rush of mud, sand, gravel, or other débris, and take immediate steps for the safety of the men as soon as such a flow is struck.

Prohibit the drinking of intoxicating liquors on property controlled by the tunnel company, institute a system of inspection to prevent any intoxicated man from working in the tunnel, and discharge habitual transgressors of this rule.

Precautions for the Foreman

Insist that the least amount of dynamite required for the work shall be used in loading the top holes. Do not go yourself or permit the men to return to the face after blasting, without examining the new roof, and upon arriving at the heading detail immediately as many men as may be required to clean the roof before any other work is attempted under it. Never fail when passing in or out of the tunnel to inspect the roof, testing any doubtful piece for possible vibration. See that any loose piece of rock is either pulled down at once or properly supported, and never take any chances by postponing the work of timbering, no matter how pressing other matters may be, because a few

minutes' delay in timbering may cost several lives. Have any timbers showing the effects of too great pressure properly relieved as soon as they *begin* to fail. When timbering is necessary close to the face, see that the front sets are thoroughly braced and blocked before firing. When the roof "breaks high" fill the space between the lagging and the roof with broken rock or blocking to prevent a large rock from crashing through the lagging upon the men beneath.

See that the men read the precautions to be taken in handling explosives, or have a copy read to them. Do not permit any instance of careless or reckless handling of explosives to go unchallenged and do not fail to discharge men for the first grave offense of this character. Never permit a man to handle dynamite recklessly, either for the purpose of scaring some one or for any other reason. See that the detonators and primers are transported to the heading in separate boxes from the rest of the supply and that they are not placed side by side after arriving. Insist that proper care be used in loading holes and that the tamping be done by pressure rather than by impact. Never allow anything but wooden bars to be used for this purpose. Do not permit a bore-hole to be loaded before it has had sufficient time to cool completely from the previous blast.

Warn the men of any change in the rate of burning of fuse. See that they do not mutilate it by rough handling or that it is not cracked or broken by placing the primer in the hole fuse-end first, or by uncoiling the fuse roughly in cold weather. Do not use fuse that has been stored or kept near a boiler, steam-pipe, or other source of heat, or that has been exposed to moisture. See that the fuse is properly coiled close to the hole before blasting, in order that it may not be torn out by blasts from a neighboring hole. Instruct the men in the proper way to prepare a primer. See that the fuse is cut squarely; that an inch or so of it is discarded; that the grains of powder do not leak out of the end that is inserted into the detonator; that the crimping is done carefully with the proper tool; that the detonator is not buried too deeply in the dynamite, and that caps of sufficient strength are used.

Always count the holes as they are blasted, and never fail to inspect the new face for evidences of missed holes. See that any such are detonated properly as soon as they are discovered, even at the possible cost of some delay. Insist that the shovelers use their picks properly when picking down the muck pile. Keep a close watch for any unexploded dynamite in the muck, and have the men do likewise; when such is found, remove it carefully to a place of safety and be particularly cautious when a piece of fuse accompanies it. Never start a new hole in the remains of one that has ever held dynamite.

When the presence of any amount of dangerous gases, either from explosives or from natural sources, is suspected, see that the men are supplied with fresh air either by opening the compressed-air line or by breaking into the ventilating pipe, if the current is in the right direction. Do not willingly remain or permit the men to remain in any atmosphere that will not support a candle-flame, because there is no way to tell how bad it may be getting after the light becomes extinguished, although a man can exist for some time in such an atmosphere. See that the men do not use anything but safety lamps or their equivalent in tunnels where explosive gases are encountered, and do not permit any means of striking an open light to be carried into such a tunnel.

Have the track and road-bed kept in as good condition as possible in order to lessen the risk of derailments. Do not permit men to ride upon loaded trains unless it is absolutely necessary, and in such cases warn them carefully as to the risk being taken. Even when the men are riding in empty cars, insist that they keep their feet and hands inside the car and that they watch carefully for low places in the roof. Never fail to discharge any driver caught "riding the chain." See that the men give an approaching train of cars plenty of room, and, if animals are used to draw them, see that the men hide their lights when the animals approach.

Warn the men of the danger from the trolley wire. Familiarize yourself with the proper means of resuscitation after an electrical shock. See that the men are not permitted to carry

on their shoulders tools or other instruments that are conductors of electricity. Inspect regularly any cables or wires for carrying electricity to lights in the heading, or any others that have to be moved frequently, and see that all worn parts are covered with insulating material or replaced if necessary. Do not permit the men to ride on electric locomotives.

See that no piles of combustible rubbish are allowed to accumulate underground, and do not permit the use of candles or torches in the vicinity of hay or other inflammable substances. Do not fail to discharge any men guilty of leaving candles or torches burning near timbers, and especially of wedging a candle between two nails driven into a post.

Exercise special precautions when approaching a place where an inrush of water is to be expected.

Be particularly cautious about drunkenness. Note the men when coming on shift and do not permit even slightly intoxicated men underground; if such a man is discovered in the tunnel, send him to the surface at once. Discharge those who are habitual offenders in this respect.

Precautions for the Miner

Do not return to the face of the tunnel without testing the newly exposed roof for loose rocks, and if any such are discovered either clean them down yourself or report them to the foreman. Form the habit of carefully examining the roof as you pass in and out of the tunnel, testing doubtful places for vibration; call the foreman's attention at once to any ground that you think should be timbered or to any timbers that need relieving to prevent their breaking.

If you are called upon to use dynamite, do so with great care, observing the precautions outlined in previous paragraphs. Never attempt to scare any one by reckless handling of explosives, and never treat dynamite with roughness or rely in any other manner upon its not exploding. Never place or carry detonators or primers and the rest of the supply of dynamite for the round in the same box or bundle. If it is your duty to assist in the loading of the holes, do this with care, using pressure

rather than a blow to tamp the powder in the hole, and always be careful not to use too much force in pushing it.

Inquire as to the rate at which the fuse burns, especially when a new brand is being tried, and see that the fuse is cut long enough to give you and your companions time to reach a place of safety. Protect the fuse from mechanical injury, such as scraping, blows, or too great pressure either from falling rocks or from the bar when tamping the hole; never use a fuse that has been thus damaged. Never reload a bore-hole before it has had time to cool. Do not use fuse that you know has been stored near a boiler, steam pipes, or other source of heat, or one that has been exposed to moisture. If you prepare the primer, see that an inch or so is cut squarely from the end of the fuse before it is put into the detonator; that no powder runs out of the end of the fuse during this process; and that the detonator is properly crimped around the fuse. Under no circumstances use anything but the regular crimping tool for this purpose.

Always inspect each new face for evidences of a misfire, and if one is discovered, call the foreman's attention to it immediately, so that he may have it detonated. Never attempt to pick out the material from such a hole; either explode it with a primer, or, if this cannot be done, drill and fire another hole at least two feet away. Use great care in removing any unexploded dynamite from the muck pile and be especially cautious if a piece of fuse is discovered near it, for this may show that there still is a detonator in the cartridge. Never handle a pick like a sledge hammer; pull or scrape the material down rather than strike it with the pick. Do not start a new hole in the remnants of a former one that has ever held dynamite, for there is always a chance that it may not have been detonated.

Whenever you feel that you are inhaling fumes from dynamite that has burned, or any other harmful gases, try to get to fresh air as soon as possible; the quickest way to do this is often to open the compressed-air line, or to break down the ventilating pipe if you know that the current is in the right direction. Never use anything but a safety lamp or its equivalent in a tunnel

where explosive gases are known to exist, and do not carry any other means of striking a light into such a tunnel.

Never attempt to ride upon a full car or a loaded trip; and when riding in an empty car see that your feet and hands are well inside and your head is low enough to clear the roof at all places. Learn which side of the tunnel has the most room and always take all of it you can when a trip of cars approaches. If it is drawn by an animal, hide any bright light you may be carrying. If it is your duty to drive a horse or mule or to run a locomotive, try to do everything possible to prevent derailments; report any places where the track or road-bed is in bad condition. Remember that the front end of the trip is the most dangerous place you can occupy, so that if this is necessary, you must take extra care; never under any circumstances ride with one foot on the chain by which the cars are being pulled. Take care that the animal does not step on you or kick you, and speak to him before approaching him from the rear. In placing a derailed loaded car back upon the rails, take care not to strain or otherwise injure yourself in so doing; keep your feet and hands in a safe position and see that the car does not topple over and crush you against the sides of the tunnel.

Bear constantly in mind that the trolley wire is dangerous, and that you must pass within a few inches of it when going in and out of the tunnel, often when your attention must be given to your footing. This is especially true when you climb into cars. Never carry on your *shoulders*, when in a tunnel where there is a trolley wire, tools or drill steel or anything else that is of metal or wet. Do not handle any electrical equipment unnecessarily, nor ride on electric locomotives. Never cause any one to receive an electric shock; it is never possible to foretell its results. If it is your duty to repair electrical apparatus, see that you are properly insulated, or that the current is cut off and cannot be turned on without your knowledge; keep your hands and body in such a position that a recoil from an accidental shock will throw you clear of any charged part of the apparatus. In removing and replacing the temporary cluster of electric lights in the heading, be careful not to touch any bare or injured place in the wires and

call the foreman's attention to any damaged place you may discover. Familiarize yourself with the methods of reviving a person injured by electric shock, and put them into practice *as soon as possible,* whenever necessity occurs.

Do not smoke or throw a lighted match near any pile of inflammable rubbish either in a building or near timbering, and do not carry a candle or a torch near any piles of hay. Never wedge a candle between two nails on a post or other piece of timber; many disastrous mine fires have started in just this way.

Never take a drink of liquor before or during working hours, and do not hesitate to report any man you see doing so or who is in an intoxicated condition; your safety and perhaps your life may be sacrificed to his carelessness when under the influence of liquor.

CHAPTER XVI

COST OF TUNNEL WORK

FROM the viewpoint of publicity, the cost of tunneling is perhaps the most neglected feature of the work. Although the last ten or fifteen years have witnessed a very considerable amount of tunnel driving, and there is presumably a large amount of cost data in existence, and although the articles describing methods, equipment, and other features of many of these tunnels have been numerous, only very few data regarding the cost of the work, which is a very practical means by which the efficacy of methods and equipment can be measured, have found their way into the ordinary channels of publicity—the engineering periodicals. This is possibly due in part to the prejudice entertained by some contractors and tunnel men against a publication of their cost data; in other cases the men actually do not know what the work has cost them, aside perhaps from the difference between their bank account at the beginning and at the end of the job; while others possibly are unwilling to go to the trouble (for it does involve extra labor) of preparing such matter for the magazines or other publications.

In an attempt to remedy this condition somewhat, there are set forth on the following pages as complete and accurate data as could be obtained, showing the cost of various phases of tunnel work at a number of different tunnels. Although the writers have not had the advantage of auditing the books from which these figures were taken, and hence cannot vouch personally for the absolute accuracy of the figures, the data were in all cases secured from persons in charge or those who were in a position to know what the work actually cost. Accompanying the figures is a brief list of the more important features of the tunnel, without which it is impossible to make even an approximate comparison between any two pieces of tunnel work.

CORONADO TUNNEL

Location: Metcalf, Arizona.
Purpose: Mine development and transportation.
Cross section: Square.
Size: 9 by 9 feet.
Length: 6,300 feet.
Rock: Granite and porphyry.
Type of power: Steam, with crude oil as fuel
Ventilation: Pressure blower.
Size of ventilating pipe: 12 inches.
Drills: 3 pneumatic piston drills for the first half of the tunnel, 3 pneumatic hammer drills for the last half.
Mounting of drills: Horizontal bar.
Number of holes per round: 21 in granite, 17 in porphyry.
Average depth of round: 6 feet.
Number of drillers and helpers per shift: 3 drillers, 1 helper.
Number of drill shifts per day: 3.
Explosives: 60 per cent. and 100 per cent. gelatine dynamite.
Number of muckers per shift: 4 to 6.
Number of mucking shifts per day: 3.
Type of haulage: Mules.
Maximum progress in any calendar month: 606 feet, June, 1913.
Average monthly progress: Approximately 415 feet.

COST OF DRIVING CORONADO TUNNEL

Month	Footage	Labor	Supplies	Total
June, 1912	117	$12.60	$16.44	$29.04
July	340	10.43	5.45	15.88
August	531	9.60	3.62	13.22
September	303	13.95	7.65	21.60
October	345	14.82	7.65	22.47
November	290	16.46	11.78	28.24
December	328	14.73	10.87	25.60
January, 1913	295	18.04	17.78	35.82
February	312	16.24	12.00	28.24
March	505	13.28	8.51	21.79
April	442	14.07	9.05	23.12
May	420	15.61	10.38	25.99
June	606	12.35	9.03	21.30
July	573	12.32	9.52	21.84
August	392	12.36	6.16	18.52
Average	...	.....	.....	$22.64

DETAILED COSTS, CORONADO TUNNEL

5,799 Feet

Labor	Cost per Foot of Tunnel	
Machine men	$2.918	
Mucking	3.399	
Tramming and dumping	1.001	
Power-house	0.791	
Track and temporary timbering	0.485	
Tool-dressing	0.461	
Supervision	0.334	
Repairs to equipment	0.625	
Equipment installation	1.740	
General	0.756	
Total labor	$13.512	$13.512
Supplies		
Explosives	$2.820	
Fuel oil	2.280	
Drill parts	0.612	
Stock feed	0.185	
Water	0.195	
Temporary timber	0.330	
Candles and carbide	0.150	
Car repair parts	0.095	
Electrical supplies	0.143	
Blacksmith coal	0.100	
Lubricants	0.158	
Iron, sheet steel, etc	0.123	
Belting, hose, etc	0.127	
Building material	0.148	
Drill steel	0.290	
Miscellaneous	0.357	
Total supplies	$8.124	$8.124
Depreciation		
Machine drills (50%)	$0.274	
Track material (25%)	0.240	
Pipe and fittings (50%)	0.388	
Drill-sharpener (25%)	0.039	
Pumps (25%)	0.011	

Depreciation		
Motors and blowers (25%)	$0.030	
Compressor (5%)	0.013	
Boilers (5%)	0.013	
Total depreciation	$1.008	$1.008
Total average cost of tunnel		$22.64

GUNNISON TUNNEL

Location: Montrose, Colorado.
Purpose: Irrigation and reclamation.
Cross-section: Horse-shoe.
Size: 10 feet wide at the bottom; 10 feet 6 inches wide at the spring line; 10 feet high at the spring line; 12 feet 4 inches high at the center of the arch.
Length: 30,645 feet.
Rock: Chiefly metamorphosed granite with some water-bearing clay and gravel, some hard black shale, and a zone of faulted and broken material.
Type of power: Steam.
Ventilator: Pressure blower.
Size of ventilating pipe: 17 inches.
Drills: Pneumatic, hammer at first, four drills in the heading; pneumatic, piston to finish, four drills in the heading.
Mounting of drills: Horizontal bar for the hammer drills; vertical columns for the piston drills.
Number of holes per round: 20 to 24 in the heading (approximately one-half of the tunnel).
Average depth of round: 6 to 7 feet.
Number of drillers and helpers per shift: 4 drillers and 2 helpers.
Number of drill shifts per day: 3.
Explosive: 60 per cent. gelatin dynamite, with some 40 per cent.
Number of muckers per shift: 5 to 8.
Number of mucking shifts per day: 3.
Type of haulage: Electric.
Wages: Drillers, $3.50 and $4.00; helpers, $3.00 and $3.50; muckers, $2.50 and $3.00; blacksmiths, $3.50 and $4.00; motormen, $3.00; brakemen, $2.50 and $3.00; power engineers, $4.00.
Maximum progress in any calendar month: 449 feet.
Average monthly progress: 250 feet, approximately.

COST OF DRIVING THE GUNNISON TUNNEL

	Cost per Foot of Tunnel
10,019 feet driven by undercut heading and subsequent enlargement	$87.23
20,626 feet driven by top heading and bench	62.18
Average cost of excavation of entire tunnel	$70.66

These costs include all labor, all materials, all repairs, all power, depreciation figured as 100 per cent. on all equipment, with a proportionate charge for general (supervisory) and miscellaneous expenses of the entire reclamation project.

LARAMIE-POUDRE TUNNEL

Location: Home, Colorado.
Purpose: Irrigation.
Cross-section: Rectangular.
Size: 9½ feet wide by 7½ feet high.
Length: 11,306 feet.
Rock: Close-grained red and gray granite.
Type of power: Hydraulic at the east end, electric at the west.
Ventilator: Pressure blower.
Size of ventilating pipe: 14 and 15 inches.
Drills: 3, pneumatic hammer.
Mounting of drills: Horizontal bar.
Number of holes per round: 21 to 23.
Average depth of round: 10 feet at first; 7 to 8 feet later.
Number of drillers and helpers per shift: 3 drillers, 2 helpers.
Number of drill shifts per day: 3.
Explosive: 60 per cent. gelatine dynamite, with some 100 per cent. in the cut holes.
Number of muckers per shift: 6.
Number of mucking shifts per day: 3.
Type of haulage: Mules.
Wages: Drillers, $4.50; helpers, $4.00; muckers, $3.50; blacksmiths, $5.00; drivers, $4.50; dumpmen, $3.50.
Maximum progress in any calendar month: 653 feet, March, 1911.
Average monthly progress: 509 feet (for the 16 months when complete plant operated).
Special features: Inaccessibility; the tunnel was located about 60 miles from the nearest railroad siding and the roads were mountainous and very steep in places.

COST OF DRIVING THE LARAMIE-POUDRE TUNNEL

11,306 Feet

	Per Foot of Tunnel
Superintendents and foremen	$1.50
Drilling	4.47
Mucking and loading	4.92
Tramming and dumping	4.63
Track and pipe	.47
Power house	.35
Blacksmithing	.84
Repairs	.47
Bonus to workmen	1.75
Maintenance of camps, buildings, and fuel	.62
Machinery repairs	.12
Air drills and parts	1.33
Picks, shovels, and steel	.84
Explosives	4.50
Lamps and candles	.42
Oil and waste	.38
Blacksmith supplies	.53
Liability insurance	.81
Office supplies, telephone, and bookkeeping	.86
	$29.81
Permanent equipment (less approx. 10 per cent. salvage)	9.73
	$39.54

The permanent equipment included power plant, camp buildings and furnishing, pipes, rails, etc.

LOS ANGELES AQUEDUCT

Little Lake Division, Tunnels 1 to 10A

Location: Inyo County, California.
Purpose: Water supply, power, and irrigation.
Cross-section: See Figure 6, p. 41.
Size: See Figure 6, p. 41.
Type of power: Electric power purchased at a nominal cost per kilowatt-hour from a hydraulic plant constructed and owned by the acqueduct.
Ventilators: Pressure blowers.

Size of ventilating pipe: 12 inches.
Drills: Pneumatic hammer, usually 2 in each heading.
Mounting of drills: Horizontal bar.
Number of holes per round: Usually 14 to 16.
Average depth of round: 6 to 10 feet.
Number of drillers and helpers per shift: 2 drillers and 2 helpers.
Number of drill shifts per day: Usually 1, but sometimes 2.
Explosive: 40 per cent. gelatine dynamite, with some 20 per cent. and some 60 per cent. Ammonia dynamite also tried.
Number of muckers per shift: Usually 5.
Number of mucking shifts per day: 1 usually, but 2 when 2 drill-shifts were employed.
Type of haulage: Tunnels 1 to 3N, mules; tunnels 3S to 10AN, electric; tunnel 10AS, mules.
Wages: Drillers and helpers, $3.00; muckers, $2.50; blacksmiths, $4.00; helpers, $2.50; motormen, $2.75; dumpmen, $2.50.

COST OF DRIVING TUNNEL 1-B-S, 1,341 FEET

Driven through medium hard granite at an average speed of 225 feet per month*

	Cost per Foot of Tunnel
Excavation	$9.15
Engineering	.18
Adit proportion	.28
Permanent equipment (estimated)	2.35
Timbering (857 feet)	1.02
	$12.98

In this tunnel, as in all of the tunnels of this division and of the Grapevine division, the cost of excavation includes the wages of the following: Shift foremen, drillers, helpers, muckers, motormen or mule drivers, dumpmen, blacksmiths and helpers, machinists, electricians (part), and power engineers.

It also includes the cost of the following supplies: Powder, fuse, caps, candles, light globes, machine oil, blacksmith supplies and fuel, and machinists' supplies.

It also includes the cost of power and of repairs for power, haulage, compressor, and ventilating machinery.

"Engineering" includes the cost of giving line and grade, etc.

* The average speed given is computed on the basis of one heading per month.

"Adit proportion" is a proportionate charge per foot of tunnel to defray the cost of an adit from the surface to the tunnel line.

"Permanent equipment" costs were not segregated for each tunnel, but were compiled for the whole division, so that the charge represents a proportionate charge per foot for the entire division cost, without salvage, of the following: Trolley and light lines, including freight and cost of installation; pressure air lines with freight and installation; ventilating lines with freight and installation; water lines with freight and installation; mine locomotives and cars, picks, shovels, drills and drill-sharpeners, with repairs for the last four items.

COST OF DRIVING TUNNEL 2, 1,739 FEET

Driven through medium granite, but very wet, at an average speed of 170 feet per month.

	Cost per Foot of Tunnel
Excavation	$8.81
Engineering	.19
Adit proportion	.34
Permanent equipment	2.35
Timbering (1,590 feet)	3.28
	$14.97

COST OF DRIVING TUNNEL 2-A, 1,322 FEET

Driven through medium granite at an average speed of 150 feet per month.

	Cost per Foot of Tunnel
Excavation	$8.05
Engineering	.16
Adit proportion	.34
Permanent equipment	2.35
Timbering (1,322 feet)	2.51
	$13.41

COST OF DRIVING TUNNEL 3-N, 1,148 FEET

Driven through medium hard granite at an average speed of 150 feet per month.

	Cost per Foot of Tunnel
Excavation	$10.00
Engineering	.23
Adit proportion	.51
Permanent equipment	2.35
Timbering (956 feet)	2.44
	$15.53

COST OF DRIVING TUNNEL 3-S, 1,358 FEET

Driven through granite of variable hardness, and containing pockets of carbon dioxide gas, at an average speed of 155 feet per month.

	Cost per Foot of Tunnel
Excavation	$12.38
Engineering	.28
Adit proportion	.16
Permanent equipment	2.35
Timbering (1,244 feet)	3.28
	$18.45

COST OF DRIVING TUNNEL 3 COMPLETE (3 N AND 3 S) 4,044 FEET

Driven through decomposed granite of medium hardness, dissected by slips and talcose planes requiring timber where ground was wet, and also containing pockets of carbon dioxide gas, making work difficult and requiring extra provisions for ventilation. Average speed, 140 feet per month.

	Cost per Foot of Tunnel
Excavation	$12.67
Engineering	.24
Adit proportion	.35
Permanent equipment	2.35
Timbering (3,570 feet)	2.71
	$18.32

COST OF DRIVING TUNNEL 4, 2,033 FEET

Driven through medium to hard granite at an average speed of 145 feet per month

	Cost per Foot of Tunnel
Excavation	$12.00
Engineering	.24
Adit proportion	.16
Permanent equipment	2.35
Timbering (1,705 feet)	2.16
	$16.91

COST OF DRIVING TUNNEL 5, 1,178 FEET

Driven through medium to very hard granite at an average speed of 120 feet per month

	Cost per Foot of Tunnel
Excavation	$11.10
Engineering	.21
Adit proportion	.08
Permanent equipment	2.35
Timbering (916 feet)	1.83
	$15.57

COST OF DRIVING TUNNEL 7, 3,596 FEET

Driven through basic biotite granite of variable hardness at an average speed of 140 feet per month

	Cost per Foot of Tunnel
Excavation	$13.55
Engineering	.27
Adit proportion	.13
Permanent equipment	2.35
Timbering (2,609 feet)	3.60
	$19.90

COST OF DRIVING TUNNEL 8-S, 1,334 FEET

Driven through medium to hard granite at an average speed of 135 feet per month

	Cost per Foot of Tunnel
Excavation	$12.82
Engineering	.19
Adit proportion	.18
Permanent equipment	2.35
Timbering (126 feet)	.39
	$15.93

COST OF DRIVING TUNNEL 9, 3,506 FEET

Driven through medium to hard granite at an average speed of 195 feet per month

	Cost per Foot of Tunnel
Excavation	$12.19
Engineering	.18
Adit proportion	.07
Permanent equipment	2.35
Timbering (305 feet)	.29
	$15.08

COST OF DRIVING TUNNEL 10, 5,657 FEET

Driven through medium to hard granite at an average speed of 200 feet per month

	Cost per Foot of Tunnel
Excavation	$13.50
Engineering	.19
Permanent equipment	2.35
Timbering (194 feet)	.11
	$16.15

COST OF DRIVING TUNNEL 10-A-N, 1,496 FEET

Driven through medium to hard granite at an average speed of 165 feet per month

	Cost per Foot of Tunnel
Excavation	$13.02
Engineering	.13
Permanent equipment	2.35
Timbering (24 feet)	.78
	$16.28

COST OF DRIVING TUNNEL 10-A-S, 2,200 FEET

Driven through medium to hard granite at an average speed of 200 feet per month

	Cost per Foot of Tunnel
Excavation	$12.37
Engineering	.20
Permanent equipment	2.35
Timbering (215 feet)	1.15
	$16.07

Grapevine Division, Tunnels 12 to 17-B

Location: Kern County, California.
Purpose: Water supply, power, and irrigation.
Cross-section: See Figure 6, p. 41.
Size: See Figure 6, p. 41.
Type of power: Electric power purchased from aqueduct plant.
Ventilators: Pressure blowers.
Size of ventilating pipe: 12 inches.
Drills: Pneumatic hammer, usually 2 in each heading.
Mounting of drills: Horizontal bar.
Number of holes per round: Usually 18 to 20.
Average depth of round: 6 to 8 feet.
Number of drillers and helpers per shift: 2 drillers and 2 helpers.
Number of drill shifts per day: Usually 2.
Explosive: 40 per cent. ammonia dynamite, but 60 per cent. and 75 per cent. gelatine dynamite were employed in hard ground.
Number of muckers per shift: 4 or 5.
Number of mucking shifts per day: Usually 2.
Type of haulage: Electric after the first 400 to 500 feet.
Wages: Drillers and helpers, $3.00; muckers, $2.50; blacksmiths, $4.00; helpers, $2.50; motormen, $2.75; dump men, $2.50.

COST OF DRIVING TUNNEL 12, 4,900 FEET

Driven through hard granite at an average speed of 185 feet per month

	Cost per Foot of Tunnel
Excavation*	$22.10
Engineering*	.32
Permanent equipment	2.25
Timbering (90 feet)	.08
	$24.75

COST OF DRIVING TUNNEL 13, 1,525 FEET

Driven through hard granite at an average speed of 130 feet per month

	Cost per Foot of Tunnel
Excavation	$20.60
Engineering	.10
Permanent equipment	2.25
Adit proportion	.37
	$23.32

* These items include the same costs as for the Little Lake division, see page 334.

COST OF DRIVING TUNNEL 14, 859 FEET

	Cost per Foot of Tunnel
Excavation	$22.70
Engineering	.13
Permanent equipment	2.25
Adit proportion	.72
Timbering (22 feet)	.16
	$25.96

COST OF DRIVING TUNNEL 15, 895 FEET

	Cost per Foot of Tunnel
Excavation	$23.28
Engineering	.11
Permanent equipment	2.25
Adit proportion	2.42
	$28.06

COST OF DRIVING TUNNEL 16, 2,723 FEET

Driven through hard granite at an average speed of 145 feet per month

	Cost per Foot of Tunnel
Excavation	$20.07
Engineering	.17
Permanent equipment	2.25
Adit proportion	.55
Timbering (18 feet)	.04
	$23.08

COST OF DRIVING TUNNEL 17, 3,024 FEET

	Cost per Foot of Tunnel
Excavation	$20.47
Engineering	.21
Permanent equipment	2.25
Timbering (142 feet)	.22
	$23.15

COST OF DRIVING TUNNEL 17½, 1,345 FEET

Driven through medium to hard granite at an average speed of 225 feet per month

	Cost per Foot of Tunnel
Excavation	$19.56
Engineering	.31
Permanent equipment	2.25
	$22.12

COST OF DRIVING TUNNEL 17-A, 3,275 FEET

	Cost per Foot of Tunnel
Excavation	$18.70
Engineering	.17
Permanent equipment	2.25
Timbering (441 feet)	1.18
	$22.30

COST OF DRIVING TUNNEL 17-B, 4,915 FEET

	Cost per Foot of Tunnel
Excavation	$21.09
Engineering	.21
Permanent equipment	2.25
Timbering (163 feet)	1.90
	$25.45

Elizabeth Lake Division,

ELIZABETH TUNNEL

Location: Los Angeles County, California.
Purpose: Water supply, power, and irrigation.
Cross-section: See Figure 6, p. 41.
Size: See Figure 6, p. 41.
Length: 26,870 feet.
Type of power: Electric power purchased from aqueduct plant.
Ventilator: Pressure blower.
Size of ventilating pipe: 18 inches.
Drills: Pneumatic hammer, 3 in the south heading and 2 in the north.
Mounting of drills: Horizontal bar.
Number of holes per round: 25 in the south heading; 16 in the north heading.

Average depth of round: 8 to 10 feet.
Number of drillers and helpers per shift: 2 drillers and 2 helpers at the north end; 3 drillers and 3 helpers at the south end.
Number of drill shifts per day: 3.
Explosive: 40 per cent. and 60 per cent. gelatine dynamite.
Number of muckers per shift: 6.
Number of mucking shifts per day: 3.
Type of haulage: Electric.
Wages: Drillers and helpers, \$3.00; muckers, \$2.50; blacksmiths, \$4.00; helpers, \$2.50; motormen, \$2.75; dumpmen, \$2.50.
Maximum progress in any calendar month: 604 feet, April, 1910.
Average monthly progress per heading: 350 feet per month.

COST OF DRIVING THE NORTH HEADING, ELIZABETH TUNNEL

Driven through altered granite requiring much timbering'

13,370 feet	Cost per Foot of Tunnel
Drilling and blasting	\$11.25
Mucking and tramming	11.70
Engineering and superintendence	1.27
Drainage	.45
Ventilation	.22
Light and power	5.55
Timbering (13,031 feet)	8.48
Cost of auxiliary shaft	.93
Permanent equipment (full charge, no salvage—estimated)	3.70
	\$43.55

COST OF DRIVING THE SOUTH HEADING, ELIZABETH TUNNEL

Driven through medium to hard granite requiring but little timbering'

13,500 feet	Cost per Foot of Tunnel
Drilling and blasting	\$14.65
Mucking and tramming	11.10
Engineering and superintendence	.86
Drainage	.17
Ventilation	.41
Light and power	4.93
Permanent equipment (without salvage—estimated)	3.70
Timbering (3,424 feet)	2.19
	\$38.01

LUCANIA TUNNEL

Location: Idaho Springs, Colorado.
Purpose: Mine development and transportation.
Cross-section: Square.
Size: 8 feet by 8 feet.
Length: 6,385 feet.
Rock: Hard granite.
Type of power: Purchased electric current.
Ventilator: Pressure blower.
Size of ventilating pipe: 18 and 19 inches.
Drills: Pneumatic hammer, 3 in the heading.
Mounting of drills: Vertical columns.
Number of holes per round: 25.
Average depth of round: 8 to 9 feet.
Number of drillers and helpers per shift: 3 drillers and 2 helpers.
Number of drilling shifts per day: 1.
Explosive: 50 per cent. gelatine dynamite.
Number of muckers per shift: 3.
Number of mucking shifts per day: 1.
Type of haulage: Horses.
Wages: Head driller, \$5.00; drillers, \$4.00; nipper, \$3.50; boss mucker, \$5.00; muckers, \$4.00; drivers, \$4.00; power engineers, \$4.00; blacksmith, \$5.00.
Maximum progress in any calendar month: 263 feet, September, 1911.
Average monthly progress: 125 feet per month for the first 4,800 feet; 240 feet per month for the last 1,575 feet.

AVERAGE COST OF DRIVING THE LUCANIA TUNNEL

First 4,800 feet

	Cost per Foot of Tunnel
Labor	\$8.86
Powder	7.86
Fuse and caps	.17
Candles and oil	.21
Horse feed and shoeing	.18
Power	1.64
Repairs	.14
Tunnel equipment	2.75
Surface plant	1.25
	\$23.06

"Tunnel equipment" includes the cost of materials and installation of the pressure air line, the ventilating line, rails, ties and fittings, and the drainage ditch.

"Surface plant" includes buildings, compressor, blower, transformers, motors, and drill-sharpener.

AVERAGE COST OF DRIVING THE LAST 1,575 FEET

The contractor received $21.50 per foot to cover the cost of labor, powder, fuse, caps, candles, oil, horse feed and shoeing, power and repairs, and the installation of the tunnel equipment.

MARSHALL-RUSSELL TUNNEL

Location: Empire, Colorado.
Purpose: Mine drainage, development, and transportation.
Cross-section: Square.
Size: 8 feet by 8 feet.
Length: 11,000 feet projected; 6,700 feet driven, January 1, 1913.
Rock: Granite and gneiss.
Type of power: Purchased electric current; also a small auxiliary hydraulic plant.
Ventilator: Fan.
Size of ventilating pipe: 12 and 13 inches.
Drills: 2, pneumatic hammer.
Mounting of drills: Vertical columns.
Number of holes per round: 18 to 20.
Average depth of round: 9 to 10 feet.
Number of drillers and helpers per shift: 2 drillers and 2 helpers.
Number of drill shifts per day: 1.
Explosive: 40 per cent. gelatine dynamite with some 80 per cent.
Number of muckers per shift: 4.
Number of mucking shifts per day: 1.
Type of haulage: Horses.
Wages: Drillers, $4.00; helpers, $3.00; blacksmiths, $4.00; helpers, $3.00; muckers, $3.25; trammers, $3.75; dumpmen, $3.25; power engineer, $3.50; shooters, $3.25.
Maximum progress for any calendar month: 187 feet, June, 1909.
Average monthly progress: 125 feet.

COST OF DRIVING THE MARSHALL-RUSSELL TUNNEL

6,700 Feet

	Cost per Foot of Tunnel
Labor	$9.37
Powder, fuse, caps, and blacksmith coal	3.35
Drills, steel, and repairs (less 30 per cent. salvage)	1.34
Power	1.41
Permahent equipment and general expense (less 30 per cent. salvage on permanent equipment)	3.41
	$18.88

MISSION TUNNEL

Location: Santa Barbara, California.
Purpose: Water supply.
Cross-section: Trapezoid.
Size: 6 feet wide at the base; 4½ feet wide at the top; 7 feet high.
Length: 19,560 feet.
Rock: Shale, slate, and hard sandstone.
Ventilator: Pressure blower.
Size of ventilating pipe: 10 inches.
Drills: 1, pneumatic hammer.
Mounting of drills: Horizontal bar.
Number of holes per round: 12 to 14.
Average depth of round: 7 to 8 feet.
Number of drillers and helpers per shift: 1.
Number of drilling shifts per day: 3.
Explosive: 40 per cent. and 60 per cent. gelatine dynamite.
Number of muckers per shift: 4.
Number of mucking shifts per day: 3.
Type of haulage: Electric.
Wages: Drillers, $3.50; helpers, $3.00; muckers, $2.75; blacksmiths, $4.00; helper, $3.00; motormen, $2.75; dumpmen, $2.50; power engineers, $2.75.
Maximum progress in any calendar month: 414 feet, February, 1911.
Average monthly progress: 210 feet.

COST OF DRIVING THE SOUTH PORTAL, MISSION TUNNEL

May, 1909, to September, 1911
5,515 Feet

	Cost per Foot of Tunnel
Administration*	$1.14
Labor	9.20
Power	2.12
Explosives	1.97
Timbering (563 feet)	.30
Track and pipe	1.22
Miscellaneous supplies†	2.46
Drill parts (including steel)	1.02
Bonus	.48
	$19.91

NEWHOUSE TUNNEL

Location: Idaho Springs, Colorado.
Purpose: Drainage and transportation.
Cross-section: Square.
Size: 8 feet by 8 feet.
Length: 22,000 feet.
Rock: Idaho Springs gneiss.
Type of power: Purchased electric current.
Ventilator: Pressure blower.
Size of ventilating pipe: 18 inches.
Drills: Pneumatic hammer.
Mounting of drills: Vertical column.
Number of holes per round: 14 to 22.
Number of drill shifts per day: 1 and 2.
Explosive: 40 per cent. gelatine dynamite, with some 100 per cent. in the cut holes.
Number of muckers per shift: 3.
Number of mucking shifts per day: 1 and 2.
Type of haulage: Electric.
Wages: Drillers, $4.00 to $4.50; helpers, $3.25 to $4.00; muckers, $3.50; motormen, $3.50; dumpmen, $3.00; blacksmiths, $3.50 to $4.50; helpers, $3.00.

* Includes superintendence, office supplies, and general charges.

† Includes candles, light globes, shovels, picks, blacksmiths' supplies and fuel, and machinists' supplies.

COST OF DRIVING THE NEWHOUSE TUNNEL

	Jan. to Aug. 1909 2,233 feet	Sept. to Dec. 1909 1,098 feet	April to Aug. 1910 693 feet
Labor	$6.72	$6.98	$11.73
Explosives	4.15	3.52	4.57
Fuse and caps	.39	.36	.44
Transportation of broken rock	1.49	1.47	2.22
Power	1.99	2.16	2.82
Blacksmithing	1.57	2.61	2.00
Use of drills, repairs, and steel	1.50	2.74	2.86
Equipment, ties, rails, pipe, etc	1.74	1.78	2.19
Sundries	.79	.80	1.85
	$20.34	$22.42	$30.68

RAWLEY TUNNEL

Location: Bonanza, Colorado.
Purpose: Mine drainage and development.
Cross-section: Trapezoidal.
Size: 8 feet wide at the base; 7 feet wide at the top; 7 feet high.
Length: 6,235 feet.
Rock: Tough hard andesite.
Type of power: Steam with wood for fuel.
Ventilator: Pressure blower.
Size of ventilating pipe: 12 and 13 inches.
Drills: 2, pneumatic hammer.
Mounting of drills: Horizontal bar.
Number of holes per round: 23 to 25.
Average depth of round: 8 to 9 feet at first; 5 to 6 feet later.
Number of drillers and helpers per shift: 2 drillers and 2 helpers.
Number of drill shifts per day: 2 at first; 3 later.
Explosive: 40 per cent. and 60 per cent. gelatine dynamite (in the proportion of about 2 to 1).
Number of muckers per shift: 4.
Number of mucking shifts per day: 2 and 3.
Type of haulage: Horses and mules.
Wages: Drillers, $4.50; helpers, $3.75; muckers, $3.50; blacksmiths, $4.50; drivers, $4.50; power engineers, $4.00.
Maximum progress in any calendar month: 585 feet, July, 1912.
Average monthly progress: Approximately 350 feet.

COST OF DRIVING RAWLEY TUNNEL

6,235 Feet *

	Cost per Foot of Tunnel
Drilling and firing	$5.25
Mucking	2.16
Tramming	1.13
Track and pipe	.44
Miscellaneous underground expenses	1.44
Power plant	2.50
Blacksmithing	.73
Miscellaneous surface work	.83
General expenses	1.98
Permanent plant	3.24
Timbering (1,618 feet)	1.18
Boarding-house, debit balance	.04
	$20.92
Credit by salvage on permanent plant	1.11
	$19.81

"Drilling and firing" includes labor, powder, fuse, caps, supplies, and repairs. "Mucking," "tramming," and "track and pipe" include labor and supplies. "Miscellaneous underground expenses" includes wages of foremen, underground telephone, etc. "Power plant" includes labor, supplies, and fuel. "Blacksmithing" and "Miscellaneous surface work" include labor and supplies. "General expenses" include salaries, office supplies, telephone, etc. "Permanent plant" includes machinery and buildings, with labor of installation, steel rails, permanent supplies, and repairs. "Timbering" includes labor and supplies. The salvage on the permanent plant is approximately 50 per cent. on salable articles, such as machinery, rails, cars, etc.

ROOSEVELT TUNNEL

Location: Cripple Creek, Colorado.
Purpose: Mine drainage.
Cross-section: Rectangular, with large ditch at the side.
Size: 10 feet wide by 6 feet high.

* A more detailed statement of the cost of this tunnel may be found in Trans. Am. Inst. Mining Engineers, February meeting, 1913.

Length: 15,700 feet.
Rock: Pike's Peak granite, chiefly.
Type of power: Purchased electric current.
Ventilator: Pressure blower.
Size of ventilating pipe: 16 and 17 inches.
Drills: 3, pneumatic hammer.
Mounting of drills: Horizontal bar.
Number of holes per round: 24, usually.
Average depth of round: 6 to 7 feet.
Number of drillers and helpers per shift: 3 drillers; 2 helpers.
Number of drill shifts per day: 3.
Explosive: 40 per cent., 60 per cent., and some 100 per cent. gelatine dynamite.
Number of muckers per shift: 4, usually.
Number of mucking shifts per day: 3.
Type of haulage: Horses and mules.
Wages: Drillers, $5.00; helpers, $4.00; muckers, $3.50; power engineer, $4.00; blacksmith, $5.00; helper, $3.50; dumpman, $3.50; drivers, inside, $5.00; outside, $4.00.
Maximum progress in any calendar month: 435 feet, portal heading, January, 1909.
Average monthly progress: Portal heading, 300 feet; shaft headings, 270 feet; all headings, 285 feet.

COST OF DRIVING ROOSEVELT TUNNEL

Total cost of portal work		$111,980.06
Contractor's percentage		11,404.88
Cost of shaft headings		262,126.55
Total cost of tunnel		$385,511.49
Number of feet driven	14,167	
Average cost per foot		27.21

COST OF DRIVING THE PORTAL HEADING

Month	Footage	Cost per Foot
Feb. and March, 1908	514	$22.690
April	262	30.970
May	268	26.760
June	187	35.010
July	203	29.600
August	300	21.760
September	351	19.600
October	287	23.000

COST OF DRIVING THE PORTAL HEADING—*Continued*

Month	Footage	Cost per Foot
November	360	21.120
December	334	18.350
January, 1909	435	16.410
February	290	22.206
March	340	21.745
April	316	21.266
May	402	18.762
June (8 days)	62	40.600

COST OF DRIVING SHAFT HEADINGS

Month		Footage	Cost per Foot
October, 1908	(2 headings)	49	$105.52
November	"	141	44.38
December	"	177	40.11
January, 1909	"	261	24.06
February	"	601	23.70
March	"	639	26.256
April	"	670	25.02
May	"	552	28.34
June	"	498	27.375
July	(1 heading)	319	32.871
August	"	410	27.747
September	"	355	32.40
October	"	380	28.178
November	"	298	34.20
December	"	251	35.153
January, 1910	"	282	28.82
February	"	259	30.636
March	"	344	27.62
April	"	376	25.313
May	"	393	24.856
June	"	373	26.616
July	"	350	25.247
August	"	372	25.029
September	"	342	28.45
October	"	372	27.361
November	"	192	27.786

TYPICAL DISTRIBUTION OF EXPENSES

Portal heading, July, 1908
203 Feet

	Cost per Foot of Tunnel
Machinery and repairs	$0.61
Air drills and parts	.99
Picks, shovels, and steel	1.90
Ditch men	1.09
Explosives	6.90
Candles	.36
Oil and waste	.09
Electric power	2.06
Blacksmith supplies	.09
General expense	.16
Liability insurance	.17
Lumber ties and wedges	.01
Horses and feed	.01
Compressor men	1.79
Drillers and helpers	4.21
Blacksmiths and helpers	3.43
Muckers and drivers	4.11
Foremen	1.50
Bookkeeper	.12
	$29.60

TYPICAL DISTRIBUTION OF EXPENSES

Shaft heading, February, 1910
259 Feet

	Cost per Foot of Tunnel
Maintenance of buildings, tents, etc	$0.096
Machinery and repairs	1.158
Air drills and parts	1.930
Shovels, picks, and steel	1.930
Pipe and fittings	.193
Ditch men	1.480
Explosives	5.032
Lamps and candles	.217
Oil and waste	.252
Electric power	2.440
Blacksmith supplies	.150

TYPICAL DISTRIBUTION OF EXPENSES—*Continued*

	Cost per Foot of Tunnel
Liability insurance	.213
General expense	.342
Lumber, ties, and wedges	.119
Horses and feed	.324
Machine men and helpers	4.050
Muckers	3.065
Blacksmiths and helpers	1.362
Engineers	1.300
Pipe and track men	.675
Drivers and dumpmen	2.355
Foremen	1.753
Mine telephone	.008
Bookkeeper	.193
	$30.636

STILWELL TUNNEL

Location: Telluride, Colorado.
Purpose: Mine drainage and developmen
Cross-section: Square with ditch at side.
Size: 7 feet by 7 feet.
Length: 2,950 feet.
Rock: Conglomerate and andesite.
Type of power: Purchased electric current.
Ventilator: Fan.
Size of ventilating pipe: 10 inch.
Drills: Started with electric drills. Finished with pneumatic piston drills, using 2 in the heading.
Mounting of drills: Vertical columns.
Number of holes per round: 16.
Average depth of round: 6 to 6½ feet.
Number of drillers and helpers per shift: 2 drillers and 2 helpers.
Number of drill shifts per day: 1.
Explosive: 40 per cent. gelatine dynamite.
Number of muckers per shift: 3.
Number of mucking shifts per day: 1.
Type of haulage: Horses.
Wages: Drillers, $4.50; helpers, $4.00; muckers and trammers, $3.50; blacksmith, $4.50.
Maximum progress in any calendar month: 170 feet, August, 1904.
Average monthly progress: 150 feet (last 10 months).

COST OF DRIVING THE STILWELL TUNNEL

Fiscal Year	Footage	Cost per Foot of Tunnel
1900–01	12 feet	$23.88
1901–02	490 "	22.98
1902–03	377 "	27.94
1903–04	702 "	21.69
1904–05	1,077 "	21.19
1905–06	292 "	30.37
	2,950 feet	Average. $23.38

These costs include all labor, supplies, repairs, powder, fuse, caps, candles, tools, lubricants, and general expenses, and the total value of the electric drill plant with which the tunnel was started and the total value of the air drill plant which succeeded it, together with tunnel buildings, pipe, rails, and the ventilator, with no credit for salvage on any of this permanent equipment.

The fiscal year dated from September 30.

The tunnel was driven in 1901–02–03 with electric drills and the high cost for 1905–06 was due to station cutting where the tunnel was double size.

STRAWBERRY TUNNEL

Location: Utah and Wasatch counties, Utah.
Purpose: Irrigation and reclamation.
Cross-section: Straight bottom and walls, with arched roof.
Size: 8 feet wide by 9½ feet high.
Length: 19,100 feet.
Rock: Limestone with interbedded sandstone, and sandstone with interbedded shale.
Type of power: Electric power generated in a hydraulic plant operated in connection with the tunnel. Distance of transmission from west portal to power-house, approximately 23 miles.
Ventilator: Pressure blower.
Size of ventilating pipe: 14 inches.
Drills: Piston pneumatic, usually 2 in the heading.
Mounting of drills: Vertical columns.
Number of holes per round: 16 to 18.
Number of drillers and helpers per shift: 2 drillers and 2 helpers.
Number of drill shifts per day: 3.
Explosive: 40 per cent. gelatine dynamite.
Number of muckers per shift: 6.
Number of mucking shifts per day: 3.

Type of haulage: Electric after first 2,000 feet.
Wages: Drillers, \$3.50; helpers, \$3.25; muckers, \$2.75; motormen, \$3.25; brakemen, \$2.75; blacksmiths, \$4.00; helpers, \$2.75.
Maximum progress in any calendar month: 500 feet, November, 1910.
Average monthly progress: 320 feet per heading.

COST OF DRIVING THE STRAWBERRY TUNNEL

		Cost per Foot of Tunnel
West heading, previous to 1909	1613 feet	\$60.05
" " during 1909	3892 "	33.58
" " during 1910	5021 "	30.56
" " during 1911	3491 "	41.52
" " January to July, 1912	2382 "	36.79
East " Oct., 1911, to July, 1912	2682 "	33.04
Average for	19,081 feet	\$36.78

DETAILED COST OF DRIVING THE STRAWBERRY TUNNEL, WEST HEADING, FOR THE YEAR 1909: 3,892 Feet

	Cost per Foot of Tunnel	
Labor:		
Engineering	\$0.49	
Superintendence	.73	
Shift bosses	1.22	
Time-keepers	.36	
Drillmen and helpers	3.15	
Miners (for hand work, trimming, etc.)	.23	
Muckers	2.96	
Track and dumpmen	.74	
Mule drivers	.39	
Motormen and brakemen	.44	
Electricians and blowermen	.07	
Disabled employees	.19	
Timber men	.22	
Miscellaneous	.40	
Materials:		\$11.59
Powder, fuse, caps, etc	\$3.08	
Lumber	.29	
Oils, candles, etc	.22	
Ventilating pipe	.64	
Track, including ties	.68	
Pressure air pipe	.40	
Drill repair parts (including hose)	.18	
Miscellaneous	.19	
		5.68

	Cost per Foot of Tunnel	
Repairs:		
Machine shop expense (including labor and supplies)	$0.93	
Blacksmith shop expense (including labor and supplies)	1.22	
		$2.15
Power (all purposes)		7.65
Depreciation:		
Haulage equipment	$0.09	
General equipment	1.00	
		1.09
General expense	$3.96	
Camp expense	1.21	
Corral expense	.25	
		5.42
Total		$33.58

"General expense" includes a proportionate charge for the expenses of the Provo office, such as salaries, stationery, telephone, and supplies; also a proportionate charge for the expenses of the Washington, the Chicago, and the Supervising Engineer's offices. The Provo office covers approximately 68 per cent. of this charge, the Washington office 23 per cent., the Chicago office 2 per cent., and the Supervising Engineer's office 7 per cent.

DETAILED COST OF DRIVING THE STRAWBERRY TUNNEL, WEST HEADING, FOR THE YEAR 1910: 5,021 Feet

	Cost per Foot of Tunnel	
Labor:		
Engineering	$0.61	
Superintendence	.60	
Shift bosses	1.25	
Time-keepers	.22	
Drillmen and helpers	2.85	
Miners	.28	
Muckers	2.93	
Track and dumpmen	.71	
Motormen and brakemen	1.49	
Electricians and blowermen	.13	
Disabled employees	.16	
Timber men	.28	
Miscellaneous	.07	
		$11.58

Materials:	Cost per Foot of Tunnel	
Powder, fuse, caps, etc.	$3.52	
Lumber	.22	
Oils, candles, etc.	.20	
Ventilating pipe	.65	
Track, including ties	.74	
Pressure air pipe	.28	
Drill repair parts (including hose)	.24	
Miscellaneous	.07	
		$5.92
Repairs:		
Machine shop expense (including labor and supplies)	$0.90	
Blacksmith shop expense (including labor and supplies)	1.23	
		2.13
Power (all purposes)		5.70
Depreciation:		
Haulage equipment	$0.20	
General equipment	1.00	
		1.20
General expense	$3.32	
Camp expense	.63	
Corral expense	.08	
		4.03
Total		$30.56

DETAILED COST OF DRIVING THE STRAWBERRY TUNNEL, WEST HEADING, FOR THE YEAR 1911: 3,419 Feet

Labor:	Cost per Foot of Tunnel
Engineering	$0.45
Superintendence	.82
Shift bosses	1.65
Time-keepers	.38
Drillmen and helpers	4.07
Miners	.37
Muckers	5.13

	Cost per Foot of Tunnel	
Track and dumpmen	$2.00	
Motormen and brakemen	1.87	
Electricians and blowermen	.08	
Disabled employees	.48	
Timber men	1.72	
Miscellaneous	.05	
		$19.07
Materials:		
Powder, fuse, caps, etc	$2.61	
Lumber	.80	
Oils, candles, etc	.43	
Ventilating pipe	.77	
Track, including ties	1.52	
Pressure air pipe	.36	
Drill repair parts (including hose)	.34	
Miscellaneous	.25	
		7.08
Repairs:		
Machine shop expense (including labor and supplies)	$2.16	
Blacksmith shop expense (including labor and supplies)	1.54	
		3.70
Power (all purposes)		5.20
Depreciation:		
Haulage equipment	$1.85	
General equipment	.50	
		2.35
General expense	$3.00	
Camp expense	1.10	
Corral expense	.02	
		4.12
Total		$41.52

DETAILED COST OF DRIVING THE STRAWBERRY TUNNEL, WEST HEADING, JANUARY TO JULY, 1912: 2,382 Feet

	Cost per Foot of Tunnel	
Labor:		
Engineering	$0.36	
Superintendence	.56	
Shift bosses	1.08	
Time-keepers	.26	
Drillmen and helpers	3.08	
Miners	.43	
Muckers	4.95	
Track and dumpmen	1.55	
Motormen and brakemen	1.33	
Electricians and blowermen	.18	
Disabled employees	.48	
Timber men	2.59	
		$16.85
Materials:		
Powder, fuse, caps, etc	$2.72	
Lumber	2.13	
Oils, candles, etc	.32	
Ventilating pipe	.70	
Track, including ties	1.51	
Pressure air pipe	.30	
Drill repair parts (including hose)	.32	
Miscellaneous	.39	
		8.39
Repairs:		
Machine shop (including labor and supplies)	$1.39	
Blacksmith shop (including labor and supplies)	1.02	2.41
Power (all purposes)		3.75
Depreciation:		
Haulage equipment	$2.20	
General equipment	.50	
		2.70
General expense	$1.90	
Camp expense	.79	
		2.69
Total		$36.79

DETAILED COST OF DRIVING THE STRAWBERRY TUNNEL, EAST HEADING, OCTOBER, 1911, to JULY 1912: 2,682 Feet

	Cost per Foot of Tunnel	
Labor:		
Engineering	$0.49	
Superintendence	.77	
Shift bosses	1.36	
Time-keepers	.31	
Drillmen and helpers	3.62	
Muckers	4.03	
Track and dumpmen	2.00	
Mule drivers	.89	
Timber men	1.80	
Electricians and blowermen	.30	
Disabled employees	.09	
Miscellaneous	.21	
		$15.87
Materials:		
Powder, fuse, caps, etc	$2.67	
Lumber	.93	
Oils, candles, etc	.36	
Ventilating pipe	.45	
Track, including ties	.56	
Pressure air pipe	.12	
Drill repair parts (including hose)	.38	
Miscellaneous	.21	
		5.68
Repairs:		
Machine shop expense (labor and supplies)	$0.62	
Blacksmith shop expense (labor and supplies)	.65	
		1.27
Power (all purposes)		3.21
Depreciation:		
Haulage equipment	$0.47	
General equipment	1.02	
		1.49
General expenses	$1.86	
Camp expenses	1.35	
Corral expenses	.95	
		4.16
Pumping (labor and material)		1.36
Total		$33.04

CHAPTER XVII

BIBLIOGRAPHY

The following is a selected bibliography of tunneling and related subjects arranged by topics in chronological order.

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STEAM POWER

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CHOICE OF POWER

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AIR COMPRESSORS

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rifugal compressor and the factors that influence efficient operation; p. 185, April, 1912, 11 pages, 14 illus. Describes the application of centrifugal compressors to various kinds of work; p. 317, May, 1912, 8 pages, 7 illus. Discusses the rating of centrifugal compressors and the amount of power required for their operation.

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WIGHTMAN, L. I., "The Compressed Air Plant for Use at Mines," *Min. and Eng. World*, p. 757, April 6, 1912, 4 cols. Discusses the advantages and disadvantages of different types of air compressors, together with the difficulties encountered with pipe lines.

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COMPRESSION OF AIR

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explosives and squibs, fuse and detonators, and concludes with notes on the safe shipment and storage of explosives and the requirements of permissible explosives. Reprint of United States *Geological Survey Bulletin 423*.

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APPENDIX

OUTLINE OF TUNNEL DATA

THE following outline is intended to cover the more important features to be considered in making a tunnel examination:

GENERAL:

Name of company operating.
Head office.
Officials.
Consulting engineer.
Field superintendent.
Names and officials of former companies.
Superintendent of each.
Dates of starting, etc.

TUNNEL:

Size.
Form.
Length.
Elevation of portal.
Character of rock.
Grade.
Size and shape of water drain.
Style of timbering where necessary.
Amount of timbering.

POWER PLANT:

Description and arrangement.
Sizes of machinery.
Cost of plant.
Efficiency.
Cost of power.

COMPRESSORS:

Make.
Size.
Speed.

Rated capacity.
Actual capacity.
Efficiency.
Repairs.
Length and size of delivery pipe.
Arrangements for removing water in air.

VENTILATION:

Make of fan or blower.
Size.
Speed.
Amount of pressure or vacuum.
Rated capacity.
Actual capacity.
Efficiency.
Repairs.
Size of ventilating pipe.
Thickness of metal.
Method of jointing.
Length of sections.
Where carried in tunnel.
Distance of end of pipe from face of tunnel.
Direction of air current.
Length of time required to clear after each round of shots.

DRILLING:

Make.
Size.
Number of drills in face.
Cost of repairs.
Method of mounting.
Air pressure at drills.
Air consumption.
Number, depth, and direction of holes in each round.
Rate of drilling.
Brand, size, and form of steel used.
Durability of same.
Method of sharpening.
Number sharpened per day.
Number of drill shifts per day.
Number of drillers and helpers.
Time required in setting up drills, in drilling the round, and in taking down drills.

BLASTING:

Make of explosives.
Brand.
Size of sticks.
Strength.
Method of loading.
Tamping.
Method of firing.
Size of wire, make of battery, precautions against short circuits if electric firing is used.
Speed of fuse.
Method of igniting same.
Order of firing.
Method of making primers, and size of detonators.
Their position in the holes.
Time required to clean out holes, load, and shoot.
Temperature of rock at the face.
Temperature of dynamite when placed in the hole.
Amount of rock broken per pound of explosive.
Arrangements for storing explosives.
Arrangements for thawing explosives.

MUCKING:

Number of mucking shifts per day.
Number of muckers.
Position in which they work.
Size and form of shovels used.
Is shoveling done from tunnel floor, planks, or steel plate?
Method of handling cars in heading.
Time of loading each car.
Time of mucking for each round.

TRAMMING:

Horses, mules, electricity, or compressed air.
Gauge of tracks.
Weight of rail.
Arrangement of switches in tunnel and at face.
Dimensions of cars.
Capacity of cars.
Type of cars.
Arrangements for facilitating dumping.
Design, size, and material in wheels.
Method of oiling.

Method of coupling.
Brakes.
Repairs.
Durability.

WAGES:
Division of labor for entire work.
For each individual shift.
Class of men employed.
Wages paid each.
Details of bonus if offered.

SPEED:
Per shift.
Twenty-four hours.
Month.
Observations on contributing causes.

COST:
Labor:
Engineering.
Superintendence.
Shift foremen.
Bookkeepers.
Time-keepers.
Drillers.
Helpers.
Muckers.
Motormen.
Mule drivers.
Dump men.
Blacksmiths.
Helpers.
Machinists.
Electricians.
Power engineers.
Track men.
Carpenters.
Tram men.
Any others, stating nature of duties.

Materials:
Powder.
Fuse.

Materials (*Continued*):
- Caps.
- Candles.
- Carbide.
- Light globes.
- Timber.
- Lumber.
- Ties.
- Track.
- Ventilating pipe.
- Pressure air pipe.
- Water pipe.
- Hose.
- Machine oil.
- Shovels.
- Picks.
- Steel for drills.
- Blacksmiths' supplies.
- Blacksmiths' fuel.
- Machinists' supplies.
- Horse feed.
- Miscellaneous.

Repairs:
- Power machinery.
- Haulage equipment.
- Compressors.
- Ventilating machinery.
- Other machinery.
- Drills.
- Pipe.
- Track.
- Electric line.
- Telephone.
- Buildings.
- Picks and shovels.
- Miscellaneous.

Power, not including labor, repairs, or depreciation:
- For drilling.
- Tramming.
- Ventilating.
- Miscellaneous.

Depreciation:
- Power machinery.
- Haulage equipment.
- Compressors.
- Ventilating machinery.
- Other machinery.
- Drills.
- Pipe lines.
- Track.
- Electric line.
- Telephone.
- Buildings.
- Miscellaneous.

General expenses.

Miscellaneous expenses, stating nature.

ILLUMINATION:
- Permanent.
- Hand.

SIGNALING:
- Electric bell.
- Mine telephone.
- Other methods.

SPECIAL DIFFICULTIES:
- Water.
- Bad air.
- Loose ground.
- Poisonous gases.
- Inaccessibility.
- Excessive freight rates.
- Any others, stating nature.

CONCLUSIONS:
- Observations, commendations, and criticisms of methods employed.

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